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Papers: Original papers, furthering the objects of the society, are invited. They should be addressed to the Secretary, and their consideration by the Publications Committee will be facilitated if: (1) a brief but comprehensive outline or summary precedes or at least accompanies the completed paper; (2) manuscript and photographs are available in duplicate or triplicate; (3) original tracings or other drawings, from which copies are readily made, are available.

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VOL. 2—NO. 9 MAY 1931 (*Proceedings Vol. 27*)

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

News Letter

THE 1932 CONVENTION DATE CHANGED

Reservations and announcements had been made for the 28th Annual Convention in Washington—Wardman Park Hotel—for the week of Feb. 22, 1932. Then it was learned that the National Education Association plans to attract ten thousand school teachers to the nation's capital at that time—to compete for sight-seeing opportunities. To avoid the competition we bowed to the pedagogues and changed our dates to the week of February 29—with meetings March 1, 2, 3 and 4, 1932.

DO YOU WANT BOUND VOLUMES?

NEXT month's JOURNAL, June, will complete American Concrete Institute *Proceedings*, Vol. 27. A limited number of Proceedings pages are set aside each month to make up somewhat more than enough bound volumes to fill advance orders. If your JOURNAL issues are thumbed, ragged, perhaps lost, you may want a cloth bound, library copy of the *Proceedings*, (including *Abstracts*) with Title Page and detailed Index. Such volumes will be sent to members and regular JOURNAL subscribers at $6.00 each. The Title Page and Index will be mailed to all members and subscribers early in July so they may have these pages privately bound with their JOURNALS if that is their preference.

If members can anticipate their need for a bound volume *next year* (Volume 28, Sept. 1931 to June 1932), the book will be sent early in July 1932 to all who order *before Sept. 1, 1931 with remittance of $3.00.* This special price is for paid-in-advance-orders from members and subscribers only. The non-member price of bound volumes is $12.50. Remember three different prices for bound volumes—$12.50 to non-members; $6.00 to members, and for Vol. 28 (ready July 1932) $3.00 on paid-in-advance orders before Sept. 1, 1931.

*Fellows of the Institute**

3—Edward D. Boyer

When a cow disputes the right-of-way with a locomotive, unsuccessfully, some one has to persuade a farmer that she was a cross-eyed, wind-broken, tubercularly-inclined critter far gone with the hoof-and-mouth disease—and not, as he had hoped, a thoroughbred fighting Guernsey. A comparable situation arises whenever anything goes wrong on the job. It was probably the fault of the Architect's superintendent or of the weather, but who ever wasted expletives on other elements until the cement had been thoroughly exonerated? Some one has to see the Contractor, the Owner and the Architect, convince them that it was their exceeding good fortune to have had Atlas cement on the job, that it was the *one* saving factor in a miserable situation for which no one was to blame—tell it to them sweetly and softly and glowingly, make them *rejoice* over it. I can think of no one in the Institute who could do this with quite the artistic perfection that I imagine Edward D. Boyer imparts to this small phase of his work as chief of the Technical Department of the Atlas Portland Cement Company.*

Of course the cow problem is but a small part of the concerns of the Technical Department. The Atlas-minded public must be educated as well as charmed. The presidential address to the Institute at New Orleans bears sufficient witness to Uncle Ed's ability as an author. To this department come also all sorts of technical questions to be answered, and answered promptly, covering every possible use and misuse of cement. While most of us plug away diligently attempting to master one corner of the field, Uncle Ed passes the whole under his accustomed hand, and devotes his leisure to thinking up new uses for cement about the apartment.

Just how and when he first became interested in concrete I should like to know. He spent the early years of his life behind a drug counter.† But

*A special order of distinction to which nominations are made from among his friends and associates in the Institute work by the author of a series of biographical sketches, of which this is the third.—Editor

*Now Universal Atlas Cement Co.

†Author's note—Beware of hasty conclusions! This does not entirely account for Uncle Ed's remarkable social abilities for at the tender age of twenty he walked away with the presidency of his graduating class of over 400 at the Philadelpnia College of Pharmacy. And

"Uncle Ed" and "cement" have been synonyms in all the years that I have known either. Long before 1904 he had designed cement plants at Coplay and at Elizabeth City, Pa. In that year he joined up with Atlas, and became a charter member of the American Concrete Institute. (He nicked an enviable record by missing his first Institute convention this year.) Committee C-1 of the American Society for Testing Materials, father of the cement specification, has profited by his membership from the very beginning. Very possibly he inhaled Allentown cement dust with his first breath and, being uncommonly amiable of disposition, took a liking to it, decided then and there to be a cement man rather than a motorman when he grew up.

But these cold facts and surmises are quite unimportant. The *vital* thing is that his whole world, of one accord, calls him "Uncle Ed." We may have little to say about the selection of our parents but the majority of us are sufficiently discriminating when it comes to annexing honorary uncles. This man has a surpassing gift for imparting pleasure by his company. Behind a lordly manner dwells one of the kindliest, friendliest souls I know. Even his grumblings, that have increased with the years, are unconvincing, take on an amusing flavor of unreality. I have it from a man who has served thirteen hard years under Uncle Ed that neither he nor anyone in the department has ever been the recipient of a cross word, a harsh criticism or an impatient gesture from the boss. It is an even higher gift to be able to make folks happy in their work than it is to relieve them of it. Company executives can turn in many directions for the technical data and advice that Uncle Ed gives them, but only from him can they get it wrapped up invariably in good humor, tied with a sparkling joke, and delivered with the graciousness of a rare spirit. What would be the sad plight of golf tournaments without Uncle Ed to take away the sting of defeat by his jaunty presentation of the trophies to the unfortunate winners? How should the rising intensity of committee meetings be harmlessly discharged without his expert touch as chairman or mediator?

Edward D. Boyer has held every elective office in the Institute. His length of service far exceeds that of any other officer. As the last to have retired from the president's chair he bids fair to serve us with his wise counsel and wiser humor for many years to come.

—ARTHUR R. LORD

the fact that he tells stories convincingly in the Pennsylvania Dutch dialect must not mislead us either. He's of French Huguenot extraction. Nor his left-handed game of golf—let him argue you out of your handicaps and you'll regret it promptly!

DR. SCHOTT

A. C. I. member, Dr. Kneisel of Verein Deutscher, Portland Cement Fabrikanten E. V., announces with sorrow the death in Heidelberg, Germany, of Frederick Schott, the Honorary Chairman of that society, Honorary Doctor of the Braunschweig Technical High School and the Heidelberg University, "who during many decades was the promoter and leader of the German Portland-Cement industry."

The JOURNAL next month, June, completes Vol. 27. No publication in July and August.

A. C. I. MEMBERS

R. T. ECKERT

formerly of the Service Department, Lehigh Portland Cement Co.'s Chicago office is now with the Makin Sand & Gravel Co., Oklahoma City, Okla.

D. S. MACBRIDE

has been appointed Manager "Incor" Division in the offices of the International Cement Corporation, New York City. H. E. Hilts has succeeded D. S. MacBride as Vice President of the Lone Star Cement Company Pennsylvania at Philadelphia.

WILLIAM KLANK

formerly civil engineer, Chicago, now doing graduate work in civil engineering at the Technical University of Charlottenburg, writes that should A. C. I. members visit Berlin for the Exhibition of Building Construction and Structural Engineering this coming summer, he would be glad to meet them and help them around. His address: Care Struck, Berlin-Charlottenburg, Galvanistr., 6, Germany.

D. R. ("SPEC") COLLINS

long identified with Wisconsin concrete products manufacturing, a leader in the Wisconsin Concrete Products Association—and it a leader among such organizations; president Concrete Masonry Association, has left Milwaukee, where he was active in the Institute's Milwaukee Convention Committee, and is now at home in Adrian, Mich., as sales promotion manager of Consolidated Concrete Machinery Co.

CLOYD M. CHAPMAN

Consulting Engineer, New York City, member Board of Direction, this Institute, as Director from the Second District, has been re-elected vice-president of the American Standards Association, and will be chairman of the A. S. A. Standards Council, in charge of the technical work of the Association. Mr. Chapman was an assistant on experimental work in the private laboratory of Thomas A. Edison (member A. C. I.) in 1899; became engineer for Westinghouse, Church, Kerr & Co., in charge of design and construction and as engineer of tests.

LEE S. TRAINOR

one time A. C. I. representative Highway Research Board and active in Institute committee work on Roads, is now Chief Engineer, Construction Division, National Lime Association, Washington, D. C. Mr. Trainor, a Burlington railroad rodman in 1904, became an assistant engineer; City Engineer, Centralia, Ill., 1911-12; Marion County, Ill., Superintendent of Highways, 1913-18; Portland Cement Association (Chicago District Engineer, later manager Highways and Municipal Bureau), 1919-28; District Manager, Chicago, McEverlast Inc., 1929-30.

NEW MEMBERS

NINETEEN applicants for membership in March have been approved by the Board of Direction as follows:

Accuvad, J. G., 390 Marlborough St., Boston, Mass.

Badlani, N. R., P. W. D., Radhan, Dist. Larkana (Sind) India.

Carlon Construction Co., Oskaloosa, Ia. (Harry F. Carlon)

The Dextone Co., 1337 Dixwell Ave., Hamden, Conn. (Louis A. Falco)

Froemming Brothers Inc., 4384 N. Green Bay Ave., Milwaukee, Wisc. (B. A. Froemming)

Gibbs, F. H., c/o Municipal Supplies Ltd., 1192 University St., Montreal, Que., Canada.

Glenn, R., Oregon State College, Corvallis, Oregon.

Larsen-Morgan Co., 6th St. at Iowa, Oshkosh, Wisc. (R. W. Morgan)

N. K. Nag, Cooch Behar, Bengal, India.

Nelson, Dewey, Knollwood Road, Reading, Mass.

Noyes, Haydon T., 1 Odell Place, New Rochelle, N. Y.

Passos, Edison J., Rua Toneleiros No. 286, Casa 5, Rio de Janeiro, Brazil.

Philpott, James H., 86 Walnut St., Wabash, Ind.

Pletta, Dan H., Civil Engineering Dept., University of South Dakota, Vermillion, S. Dakota.

Rawls, E. M., 60 Montford Ave., Asheville, N. C.

Rawson, R. A., The Master Builders Co., 7016 Euclid Ave., Cleveland, Ohio.

Sharma, Hari Shankar, District Board, Meerut, U. P. India.

Scripture, Jr., Edward W., 3159 Euclid Heights Blvd., Cleveland Heights, Ohio.

Super Concrete Emulsions, Ltd., 3710 So. Alameda St., Los Angeles, Calif. (C. E. Little)

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC. REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912.

Of Journal of the American Concrete Institute published monthly except July and August at Detroit, Mich., for April, 1931.

State of Michigan } ss.
County of Wayne }

Before me, a notary public in and for the State and county aforesaid, personally appeared Harvey Whipple, who, having been duly sworn according to law, deposes and says that he is the Editor of the Journal of the American Concrete Institute and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, American Concrete Institute, 624 Fisher Bldg., Detroit Mich.; Editor, Harvey Whipple, 624 Fisher Bldg., Detroit, Mich.; Managing Editor, none; Business Manager, none.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, must be given.) American Concrete Institute, 624 Fisher Bldg., Detroit, Mich.

Duff A. Abrams, President, 342 Madison Ave., New York, N. Y.

S. C. Hollister, Vice-President, Purdue University, Lafayette, Ind.

Arthur R. Lord, Vice-President, 140 So. Dearborn St., Chicago, Ill.

Harvey Whipple, Secretary-Treasurer, 624 Fisher Bldg., Detroit, Mich.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.) None.

4. That the two paragraphs next above giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stocks, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the six months preceding the date shown above is ——. (This information is required from daily publications only.)

HARVEY WHIPPLE.

Sworn to and subscribed before me this 20th day of April, 1931.

(SEAL) ETHEL BLAINE WILSON.

(My commission expires July 30, 1934.)

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Durability of Concrete

A Report of Committee 801

A. E. Lindau, chairman

Two papers on the following pages—"Study of Defective Concrete," by F. R. McMillan and "More Lessons from Concrete Structures in Service," by Roderick B. Young—both members of Committee 801, Durability of Concrete—were presented at the 27th Annual Convention, Milwaukee, Feb. 24-26, 1931, with the following remarks by Mr. Lindau, chairman of the Committee.—Editor

It is my privilege to introduce the speakers on the assumption that I should know something about the committee work. You will notice that this number appears on the program as a Symposium by members of Committee 801, and that there are two who are "symposing," which probably reduces a symposium to its simplest terms. It was intended to be a more complex symposium than we have. There has been enough work done by the committee to fill a session; at one time the Program committee hoped that might be done, but other things intervened and we are privileged to have the two papers as here presented. The work of the committee has been going on for some time and it will probably go on for some time more. The committee has undertaken to survey structures individually and collectively. This survey has taken the members of the committee individually and in groups from, I was going to say, "Greenland's icy mountains to India's coral strands," but that is a little large; they did make a survey of structures though in what you might call the

sub-arctic regions of Canada, and continued at other times to the sub-tropical regions of our southern states, and from the Atlantic Ocean to the Pacific Ocean; so geographically they have done a big job. The committee is functioning by making these reports from time to time, as individual papers.

Readers are referred to the JOURNAL *for Nov. 1931, (Vol. 28) for discussion of the two papers which follow. Such discussion should reach the Secretary by Oct. 1, 1931.*

Study of Defective Concrete*

BY F. R. MCMILLAN†

In a survey of concrete structures representative of almost every kind of aggregate, method of construction, and condition of exposure to be found in the greater part of the United States and portions of Canada, a considerable amount of clinical material has been developed from which much can be learned both as to what to avoid and what to require to obtain more durable structures. While it is hoped later to make an extended presentation of the data from this survey, this paper will be limited to a discussion of some of the ways in which different causes of disintegration or unsatisfactory concrete are identified.

SOURCE OF INFORMATION

In a survey designed to bring out the causes of defective concrete, there are three principal sources which must be relied upon for information:

(1) Personal recollections of competent persons engaged on the work at the time of construction.
(2) Original records.
(3) The condition of the structure itself.

Personal recollections of responsible individuals are not often available and frequently none too reliable. Original records, when available, are most reliable as to the details covered, but good original construction records are very rare and seldom do they cover all the points upon which the concrete engineer of today seeks information. It is, therefore, the evidence presented by the structure itself upon which the investigator must to a large extent rely for his information. This would be somewhat discouraging if there were available for study only a few struc-

*Presented at the 27th Annual Convention, A. C. I., Milwaukee, Feb. 24-26, 1931, as part of the work of Committee 801, Durability of Concrete—see p. 1037.
†Director of Research, Portland Cement Association, Chicago.

tures representing a limited set of conditions, but as the scope of the study is extended the indications multiply rapidly until it is possible to read with considerable accuracy the causes of defective concrete in the present condition of the structure.

In reference to personal testimony, it is of interest to consider the fallibility of man's recollection as applied to details of events that transpired a dozen years before. Sometimes the personal evidence has the ring of reliability and accuracy and serves to illuminate and corroborate the evidence presented by the structure itself. Equally often the statements are not convincing and cannot be squared with findings on the ground. A desire to conceal or soften the facts is encountered sometimes. This, however, can usually be detected and the true condition revealed by a few judicious questions.

Not always is it the memory that is at fault when the recollections fail to agree with the evidence presented by the structure itself. Frequently, the memory is quite accurate as to things that were supposed to have been done, but the inexorable effect of time has disclosed that the work was not carried out as directed.

It may be pertinent to point out the desirability of making complete records of the construction operations. With a few outstanding exceptions like the structures of the Reclamation Service and the Crystal Springs Dam, it was the experience in this survey that the records available were generally disappointing.

EXAMINATION OF BOTH SOUND AND DEFECTIVE CONCRETE ESSENTIAL

In an examination of a structure, the portions which show no defects require study as well as the defective portions. The extent and position of the unaffected areas with relation to exposure and conditions of placement give important information. The general character of the surface and its variation from point to point may show conditions as they existed in the now defective portions at some previous stage. Similarly, the study of structures in which only slight defects are in evidence may provide essential information for the explanation of some other structure. The significance of these comments will be brought out in a

number of the illustrations of this discussion; as specific instances the cases of the XY building and of the Gull Lake and Pine River Dams are cited.

The XY building, not identified for obvious reasons, had shown serious spalling of the concrete jambs just inside of metal window frames and the frames were badly rusted. At the time of the inspection, the windows on the most exposed side of the building were so completely affected, that many had to be replaced and the concrete around the openings restored. Those that had not been reconditioned were in such advanced state that no explanation of the cause could be discovered. However, an examination of the sides of the building least exposed to wind and rain disclosed a number of the windows in which the development of the trouble could readily be traced through its various stages. This study showed that the trouble began from rusting of the sash on the inside at a point just above the horizontal pivot of the ventilating sash. These ventilating sash were in the upper portion of the window and when opened (top inward) permitted the rain, driven by the wind, to rebound and strike the inside of the frame. At some of the windows only the first signs of rust were showing, on others the rusting had progressed downward and upward varying distances with resulting spalling also in various degrees. Here was a complete record showing all the stages through which the other windows had passed—a record which could not have been added to by the original construction records, or by personal recollections of those engaged on the work.

Gull Lake Dam is a case where a study of a well preserved structure provides an explanation of defective conditions found elsewhere. This is one of five dams forming navigation control reservoirs in the headwaters of the Mississippi River, built by the U. S. Engineers Corps between 1902 and 1907. This is a group of structures in which the field notes spoke eloquently of the workmanship and supervision—conclusions which were later confirmed by personal discussion with the foreman in charge of the construction of all five dams.

Figs. 1 and 2 show three views of this dam which bring out both the excellent workmanship at the time of construction, and the perfect condition of the structure today. The complete absence of spalling at the water line is particularly noticeable. At

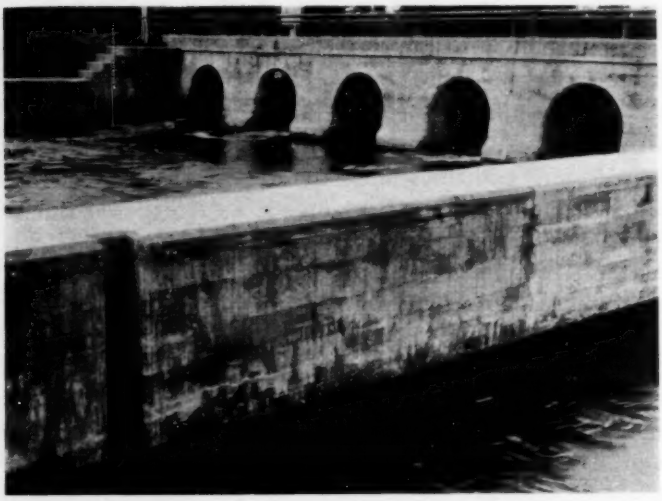

FIG. 1—GULL LAKE DAM, MINN. EXAMPLE OF GOOD CONSTRUCTION METHODS. ALMOST NO DEFECTS EVIDENT AFTER 25 YEARS

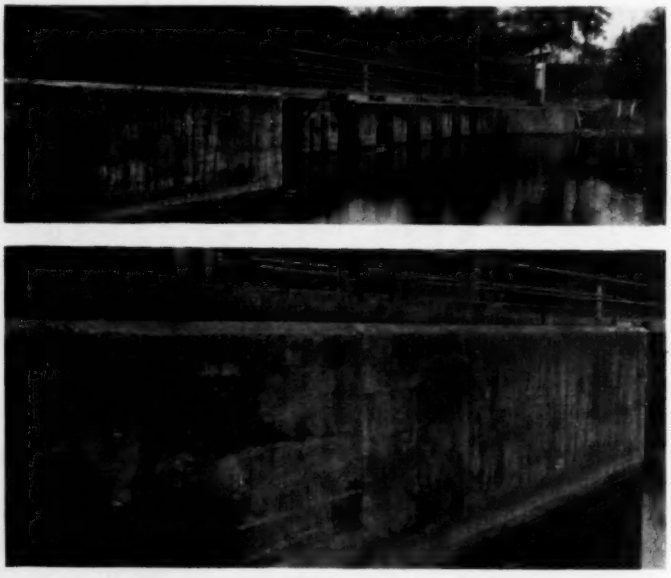

FIG. 2—DETAIL VIEWS OF GULL LAKE DAM, MINN.

the time of the inspection, it seemed important to know whether this unusual condition was due to specially good materials and workmanship, or merely to the absence of conditions which produce spalling. Such knowledge was necessary, not only to a proper understanding of this structure, but of others where such spalling is observed.

Several clearly defined water lines were in evidence (some are visible in the pictures) indicating that the reservoir level might not have been stationary long enough to produce spalling. Yet it seemed that in 22 winters in this climate some spalling would have occurred unless the concrete were unusually resistant. By close examination of the concrete below the water surface, areas were located where well-defined spalls had occurred at the corners of three of the piers. These were the characteristic V-type spalls so often found at the water surface and indicated that at some time in the past, water surface and ice conditions had been such as to produce this spalling and ravelling at the corners. The occurrence of these corner breaks at only a few places over the entire area was interpreted as showing certain defective spots in the concrete which yielded to the severe conditions, while the general excellence of the concrete was such that the disintegration was thus localized.

Another of the five dams of the Mississippi Headwaters is Pine River Dam shown in Fig. 3 in which, as in Gull Lake Dam, the presence of certain defects in an otherwise perfect structure is convincing evidence that it was the unusually good workmanship in the rest of the structure which accounts for its excellent condition after 21 years. The single defect in this dam is the calcium carbonate deposit seen in Fig. 3 on the wall of the fishway near the end where it joins the piers of the dam. This deposit shows that a slight leakage had taken place along a fill plane, forming this incrustation in exactly the same manner as similar or large deposits are formed in so many structures.

Pine River Dam has been used by the writer in a number of other discussions because it is such an outstanding example of what it is possible to obtain with careful construction methods. It was the last and noticeably the best of the group of five dams all of which were built under the supervision of Hans Olson.

FIG. 3—PINE RIVER DAM, MINN. ANOTHER STRUCTURE OF EXCELLENT RECORD DUE TO GOOD CONSTRUCTION METHODS

The method used by Mr. Olson should be made a matter of record as it is thoroughly sound in the light of our present-day knowledge of concrete mixtures, and accounts for the splendid performance which these structures have given. The proportion of sand to cement was determined by the engineer in charge by comparative tests of mortars using the available sand and standard sand. The instructions were to use with this mortar as much of the coarse aggregate as was possible and still obtain a mixture which could be worked into place, and in which there were no unfilled pockets between the coarse aggregate particles. The instructions also required placing the concrete in thin layers and thorough ramming with tampers weighing 35 lb. Only enough water was to be used to show on the surface after such thorough ramming. Mr. Olson found that the workmen were inclined to slight the tamping with these heavy tampers. By reducing these to a weight of 25 lb., he obtained much better results. He also found that he got better consolidation of the successive layers if he used somewhat more water than was intended in the instructions. When the extra water resulted in a tendency to overwetness, this was counteracted by the use of

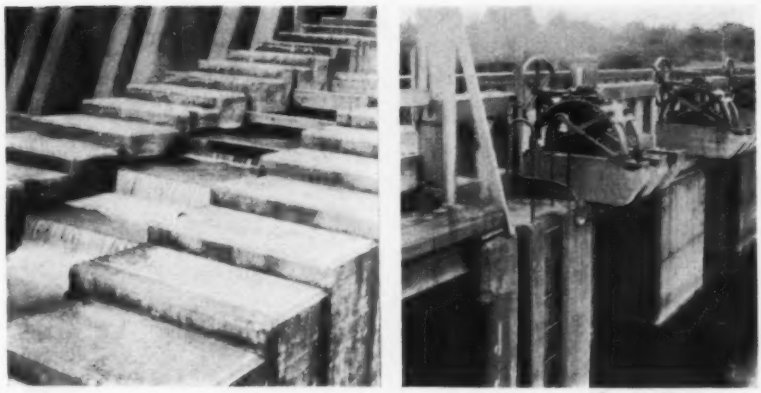

FIG. 4—DETAIL VIEWS OF PINE RIVER DAM

batches somewhat drier than the average. In this manner he obtained not only a homogeneous concrete in each layer and a thorough bonding of the layers, but avoided the undesirable accumulation of water and laitance as the placing progressed. The detail views of Pine River Dam in Fig. 4 show the excellent results from this method.

EVIDENCE OF DRY MIXES

The use of mixes too dry for proper placement or consolidation is usually quite easily detected from the appearance of the structure. The defects resulting from this cause are well illustrated in Fig. 5, which shows 2 views of the Thompson Dam near Duluth, built in 1906. This dam was described by H. C. Ash in a paper before this Institute in 1929. In the picture at the left, the failure to bond successive layers is indicated by the calcium carbonate deposits brought to the surface by water seeping along the surface between layers.

The successive layers are quite clearly marked by these incrustations. These show the irregularity which would be expected from dry mixes spread in thin layers.

The picture at the right shows two nearby sections in which the seepage between successive layers was nearly eliminated. This was accomplished by the use of a slightly wetter consistency. In the section at the left in this picture the bond between the portions

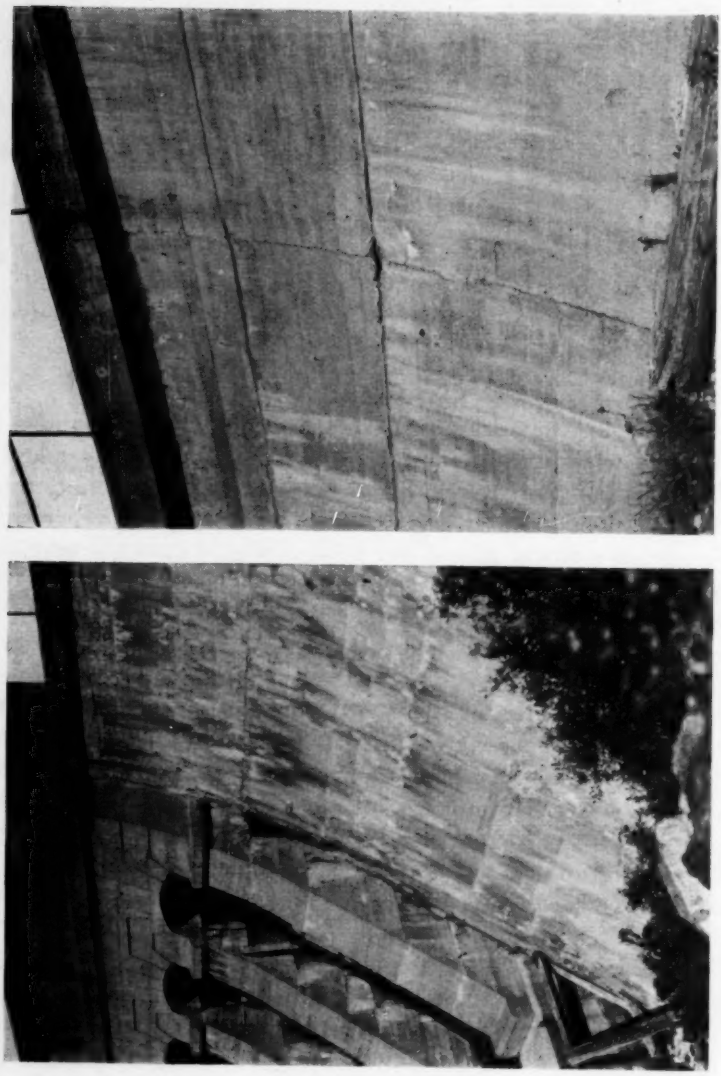

FIG. 5—THOMPSON DAM, MINN. SEE PROCEEDINGS, A. C. I., V. 25, P. 29, 1929

representing successive day's lifts was not perfect, as can be seen by the heavy incrustation of calcium carbonate below the surfaces of separation. In the section at the extreme right the bond between successive layers is perfect, and that between successive day's work is nearly so.

Mr. Ash, in his paper, makes an interesting comment on the difficulties he had in training inspectors out of the habit of insisting on too dry mixes. After the first few sections, his method, which was something like that used on Pine River Dam, was mastered and the structure completed according to his desires. The three sections to be seen in Fig. 5 show the stages in this improvement.

In considering the defects of the type illustrated in the picture at the left in Fig. 5, it must be remembered that they are principally of interest as they affect the appearance of the structure. The seepage had practically ceased years ago and the integrity of the structure has not been affected. It has been the almost universal experience in this survey of structures that where concrete placed by this dry tamped process was encountered, the structure has stood up well under all conditions even though an unsightly appearance resulted from such defects as pointed out above.

The dam shown in Fig. 6, built in northern United States in 1898, is another case where the use of dry mixtures is plainly evident. The various layers have been sharply defined by the frost action on the portion of the concrete at the lower edge of each layer. The dry, stiff mixes are difficult to work into the acute angle between the horizontal surface and the downstream face of the dam. This provides an easy point of attack from the frost action which is most pronounced at the lower edge of each layer. A lesser amount of spalling is shown at the top of each layer. The surface of this dam also shows the aggregate exposed by erosion, solvent action, and frost. Except for these surface defects this dam is in excellent condition and should continue to serve its purpose almost indefinitely.

Fig. 7 shows portions of a western dam, more than 30 years old, in a locality subject to moderate frost action. In the upper view, considerable spalling can be seen at several of the fill planes.

FIG. 6—AN EXAMPLE OF DRY TAMPED CONCRETE AFTER 30 YEARS EXPOSURE

The stiff consistency of the mixture is indicated by the steep slope of the surface marking the boundaries of successive lifts. Some undercutting where the concrete joins the rock is seen at the extreme right of the view. Aside from these defects, the entire surface is seen to be very well preserved. The discoloration is the result of a growth of moss which is quite heavy in some spots. In the lower view, the mixture was somewhat wetter as shown by the flatter slope to the fill planes, although this could not be described as a wet mix as this term is used at the present time.

It was noted above that it was the almost universal experience to find well-preserved concrete when the dry-tamped mixes were

FIG. 7—ILLUSTRATING DRY AND SEMI-DRY MIXES

used. It is significant also that where mixtures of this type were used there is less confusion as to the causes of defects. It will be brought out in what follows that in certain cases it is very difficult to determine the factors primarily responsible for the condition of the structure, but this is not the common case where the dry tamped mixes were used. This rather clearly indicates that the better concrete which is likely with the dry mixes, combined with the freedom from serious segregation obtained by this method of placing, serves to protect against deterioration from other causes such as poorly graded or dirty aggregates, or even aggregate that in less durable concrete would clearly show unsound.

Fig. 8 shows another structure in which the dry tamped concrete is evident from the irregularity of the surfaces of contact and lack of bond between successive layers. This is a Lake Michigan breakwater built about 30 years ago. In the view at the bottom, the surfaces separating the successive layers are discernible through the thin mortar protection though not so

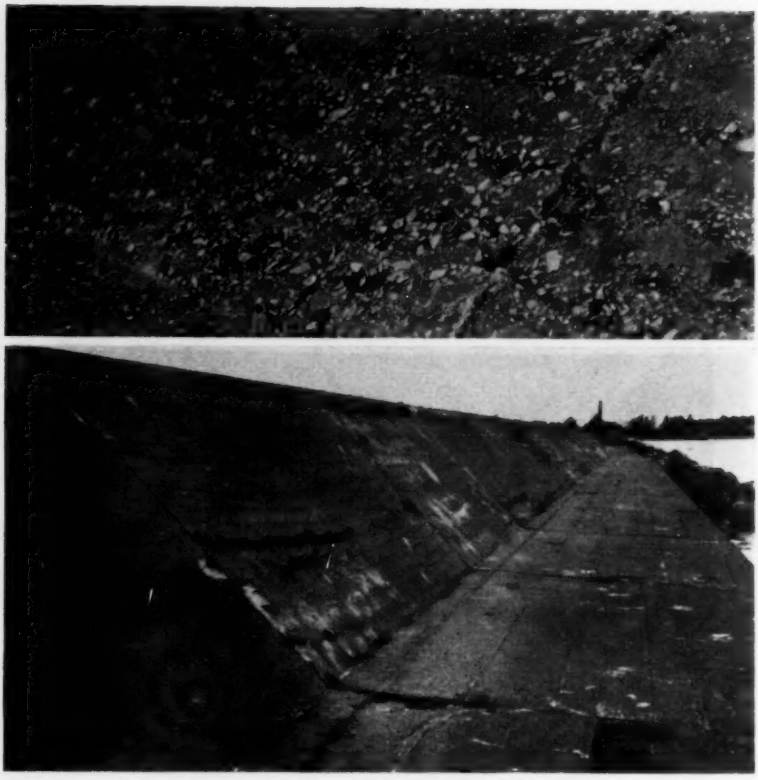

FIG. 8—A LAKE MICHIGAN BREAKWATER AFTER 30 YEARS OF SERVICE. NOTE GOOD CONDITION OF THE DRY TAMPED MIXES

readily as in the view at the top in which this thin coating is completely weathered away. Both these views show the general character of the construction resulting from this method of placing and its generally good condition after 30 years of about the severest kind of exposure.

On the horizontal surface in the lower view of Fig. 8, board marks are clearly visible. Such use of boards to protect the top surfaces of walls has been frequently encountered in structures of the period of this breakwater. Incidentally, this structure also provides a good illustration of the inaccuracy of the personal recollections of individuals in regard to details of the work. In this case the carpenter foreman who built the forms for this

FIG. 9—AN EXAMPLE OF DISINTEGRATION DUE TO UNSOUND AGGREGATE

breakwater was interviewed and stated with some positiveness that the concrete mixtures were very wet. This recollection seems to have been based on the fact that the men wore rubber boots when distributing the concrete in the form, but it is not supported by the evidence of the structure itself.

EVIDENCE OF UNSOUND AGGREGATE

Fig. 9 shows a railway pier in which a fairly advanced state of disintegration due to unsound aggregates is illustrated. It is not obvious on first sight that the appearance of the surface in this picture is indicative of coarse aggregate disintegration. As can be seen in this picture, the lower part of the pier is still in very good condition and it is only in the upper 3 ft. that disintegration has begun. In this respect conditions are similar to those in which

FIG. 10—EXAMPLE OF AN EXCELLENT STRUCTURE MARRED BY SEEPAGE AT A FEW JOINTS

overwet mixes resulting in "water gain" are responsible for the disintegration. In fact, it is quite probable that some effect of "water gain" is responsible for the conditions in this pier. As pointed out previously it often happens that several factors are responsible for conditions observed in structures and, that in many cases, poor aggregates are well preserved which in either more exposed conditions, or more permeable or porous concrete would have shown early signs of deterioration.

A condition which makes it difficult to determine how much of the disintegration in the pier in Fig. 9 is due to water gain is that the disintegration of the aggregate itself proceeds more rapidly where the contact with water is most frequent. Thus, the rain falling on top of the pier starts disintegration at this point. As the expansion and disruption of the aggregate proceeds the concrete becomes more porous and the water finds its way through this porous mass to the layers below. The process is continuous from the top down in exactly the same manner as that resulting entirely from water gain.

BONDING SUCCESSIVE LAYERS

Fig. 10 presents a characteristic defect that is easily recognized. In this structure can be seen the incrustation of calcium car-

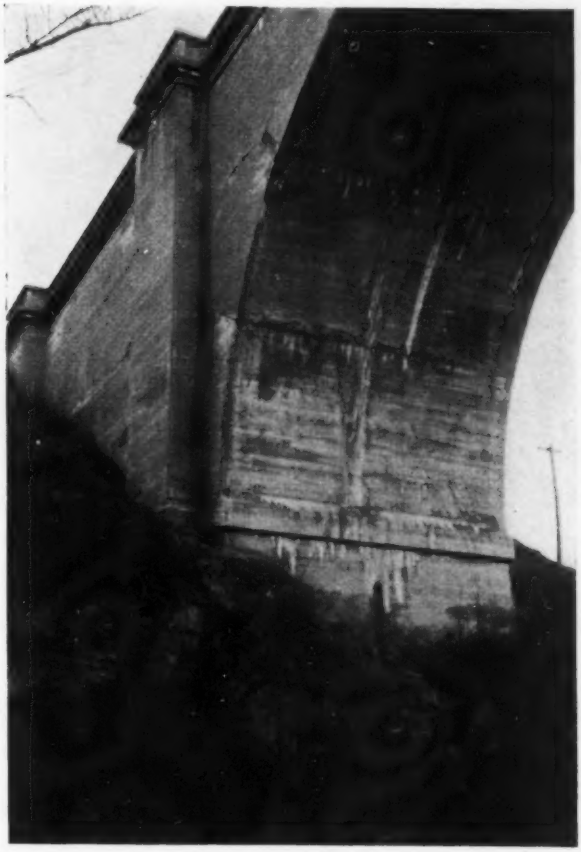

FIG. 11—STRUCTURAL DEFECT DUE TO INADEQUATE DRAINAGE

bonate which had its origin in water seeping through the joints between the successive layers. Such deposits are seen both on the intrados of the arch and on the one pier in the immediate foreground of the picture. This structure was built in 1905 and it appears from the present condition that the deposits seen in Fig. 10 have not increased materially in recent years. This means that either the joints have thoroughly sealed themselves, which is a very common condition, or that water can no longer find its way to the open seam.

Fig. 11 shows one of the arches in this structure which has

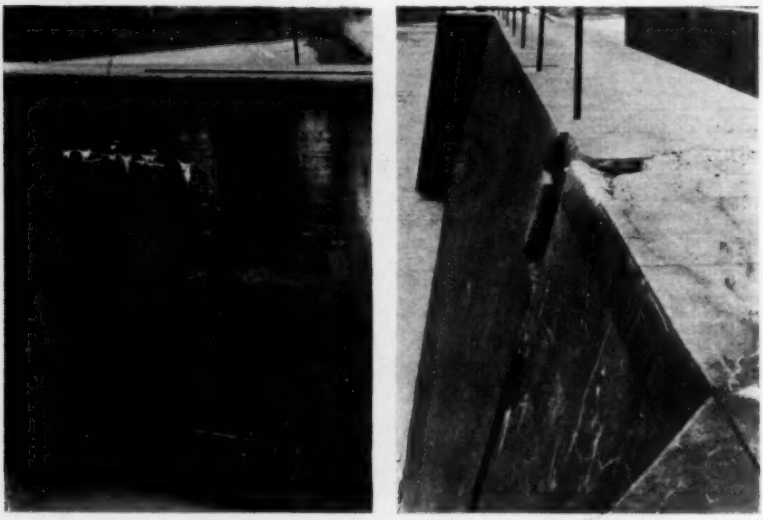

FIG. 12—A LOCKWALL WITH CORE OF LEAN CONCRETE AND FACING OF A RICHER MIX

cracked longitudinally for a portion of its length. It appears that this crack has been produced either by the hydrostatic pressure or freezing of the saturated spandrel fill. This indicates the necessity for proper drainage in this spandrel space. The fact that it has been confined to only a few of the arches in this long structure indicates that, in general, the provisions in this respect were successful. Similarly, the complete freedom from seepage at most of the other joints in the structure indicates that the methods employed for obtaining the proper bond through successive layers were generally successful.

STRUCTURES FACED WITH A RICHER MIXTURE

A condition frequently encountered is where a concrete structure is faced with a somewhat richer mixture to provide greater resistance to the weather. In some of the earlier structures this type of construction was very common. While there are successful structures of this type there are cases where the outer shell has cracked badly and separated from the interior. In such failures of this type as have been encountered, the outer shell has been relatively thin and of concrete very much richer than the inner mass.

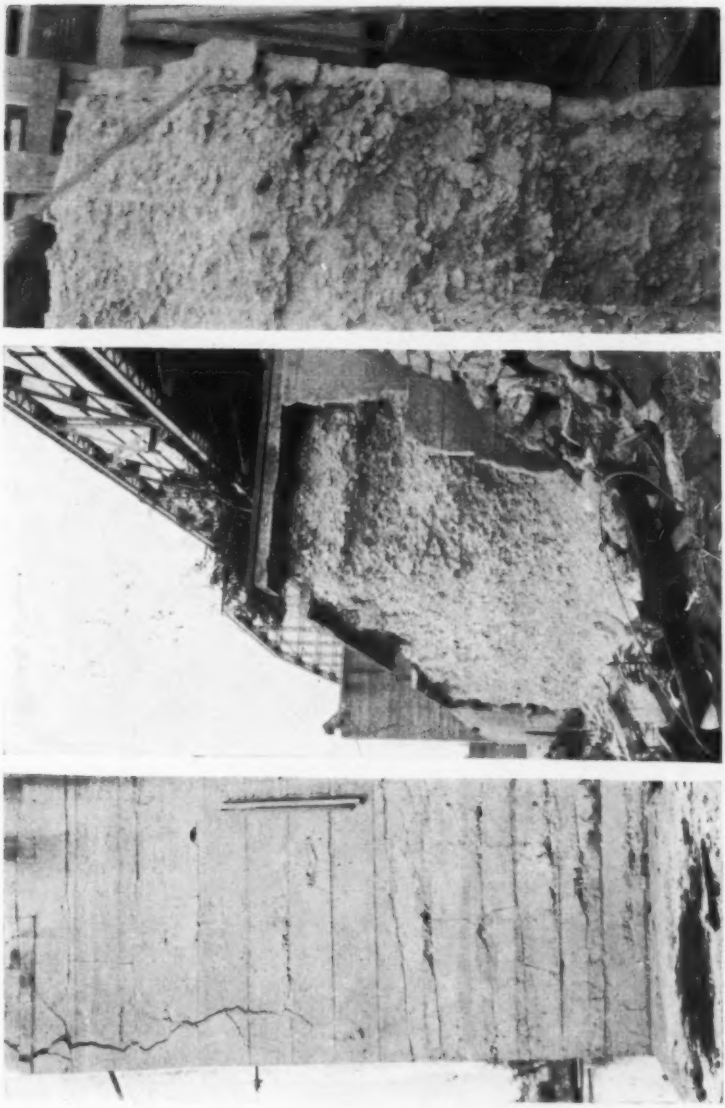

FIG. 13—EXAMPLE OF LEAN CONCRETE FACED WITH A RICHER MIXTURE

FIGS. 14 AND 15—TWO VIEWS OF A DAM OF VERY LEAN MIXTURE IN MILD CLIMATE

Figs. 12 and 13 show two prominent examples of this type of construction. Fig. 12 is a lock wall built in 1904 and 1905. Except for the very prominent cracking which is clearly seen in the two views, the exterior concrete is in excellent condition. In the view at the right, small portions of this outer shell have been broken away. Fig. 13 shows three views of another lock wall built between 1895 and 1899. In the view at the left a portion of the outer wall is seen in which the shell is badly cracked but still in position on the wall. In the central view is seen a section of the wall where the outer shell has completely broken away and the mass concrete within badly weathered. The view at the right shows a point where a section of the wall has been cut away to provide for extensions to the structure. The extremely lean character of the mass concrete and the dense character of the outer shell is brought out very well in this view.

The feature it is particularly desired to emphasize in Fig. 13 is the character of the cracking shown in the picture at the left. The large spacing between the cracks, their large size and regularity of occurrence is typical of incipient failure in this type of construction.

QUANTITY OF CEMENT

Evidence as to the quantity of cement used in the mixture is the most difficult to obtain from an examination of the structure. An extremely lean mix gives a weak and porous concrete that is readily attacked by the weathering agencies. Such a result is also produced by inadequate curing. When evidence from sources other than the examination of the structure indicates a deficiency of cement, it is usually found that the defective concrete is more or less general over the structure unless there is some point of local attack such as the water line. This would naturally be the case also where curing had been neglected. The lean concrete in the wall at the center in Fig. 13 is a typical case of gross deficieney of cement. It is seen that this concrete was badly disintegrated over the whole surface once the protecting shell of rich concrete was removed. While curing may have been involved to some extent in this wall, the extreme leanness of the mix is very evident.

Another example of a lean mixture is shown in Fig. 14 and 15. These show portions of the downstream face of a dam in which a

FIG. 16—ANOTHER VIEW OF THE DAM IN FIG. 14

so-called sand cement was used. This cement was made by grinding portland cement with approximately equal parts of sand or crushed granite. The concrete was mixed in about the usual proportions for structures of this kind using the ground mixture as the cement portion, thus the actual cement content was about ½ bbl. per cu. yd. The views in Fig. 14 and 15 are typical of the worst portions of the downstream face. Fig. 16 shows most of the downstream side of this dam. From this it can be seen that there is some scaling here and there over the entire surface.

While the scaling due to these lean mixtures is quite evident, it is very much less than would be expected for the usual conditions. The two factors which account for the limited scaling for such lean mixes are the careful methods followed in placing the concrete and the mild climate to which it is exposed. This dam is in the arid region of the southwest where both rain and frost are rare occurrences.

A fairly complete construction report on this dam shows that every care was taken to secure proper bonding of new and old work and specially to compact the concrete between the plum stones and against the forms. One inspector was employed with

FIG. 17—BUTTRESS WALL BUILT IN 1908, SHOWING EFFECT OF "WATER-GAIN"

each of the placing gangs. Concrete was delivered in bottom dump buckets and plum stones were deposited immediately upon the freshly dumped concrete. This report shows also that some attention was given to the curing. The concrete was kept wet for a period of two weeks, which was none too much for exposure to the hot dry air of this region.

The success of this careful placing is shown by the fact that there has been practically no seepage into the inspection gallery, nor along the construction joints or fill planes. The complete absence of seepage on the downstream face, as shown by the photograph in Fig. 16 is a rare condition for structures of that period (1913-1916).

CONSISTENCY AND PLACING

Defects due to careless or wrong methods of placing and over-wet mixtures are the most common to be found in concrete structures. As suggested in a previous paragraph, other causes

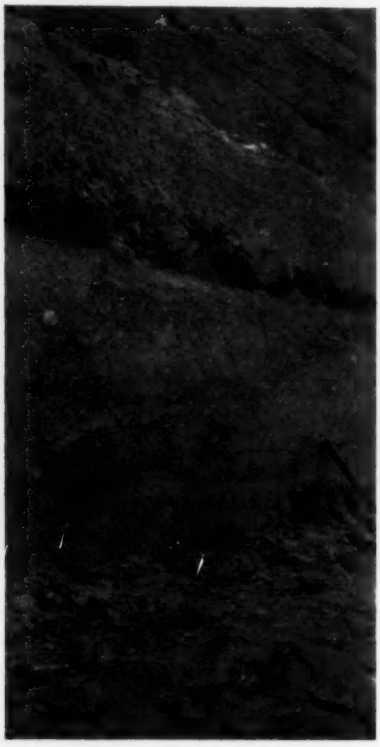

FIG. 18—PORTION OF A DAM IN SEVERE CLIMATE, ILLUSTRATING POOR CONSTRUCTION METHODS

of defects may be completely obscured by sloppy mixtures or improper placing. Evidences of "water-gain," segregation, and honeycombing are everywhere to be seen and easily identified. Closely allied with these are the cases where successive layers of concrete fail to bond properly. Sometimes these defects occur in structures where the mixtures are suitable and placing methods are otherwise satisfactory. More commonly, however, they are associated with a general carelessness in other respects. A few illustrations will suffice.

Fig. 17 shows a very common case. The stepped buttress wall, which is part of a dam in Michigan, built in 1908, provides a good

FIG. 19—ANOTHER PORTION OF THE DAM SHOWN IN FIG. 18

opportunity for water and fine material to collect during placing. The usual method is to deposit concrete in the body of the structure which allows the lighter portions of the mix to flow outward to the more distant points. The ease with which the rain and snow can collect on the steps hastens the disintegration through frost attacking the porous concrete.

Fig. 18, which shows portions of a dam in a very severe climate, is another illustration of poor construction methods. Improper mixes and segregation, due to excess water were everywhere evident on this structure. Curing also may have been neglected. The slope of the inclined fill plane to be seen just above the handle of the pick at the extreme right of the picture shows a somewhat stiffer consistency than was evident in other parts of the structure. This concrete of stiffer consistency shows much better resistance than the wetter layer just above. Fig. 19 shows another portion of this dam. In this view also the concrete of stiff consistency shown immediately above the badly honeycombed area, is re-

FIG. 20—TWO-FT. LAITANCE BED RESULTING FROM PLACING CONCRETE THROUGH WATER

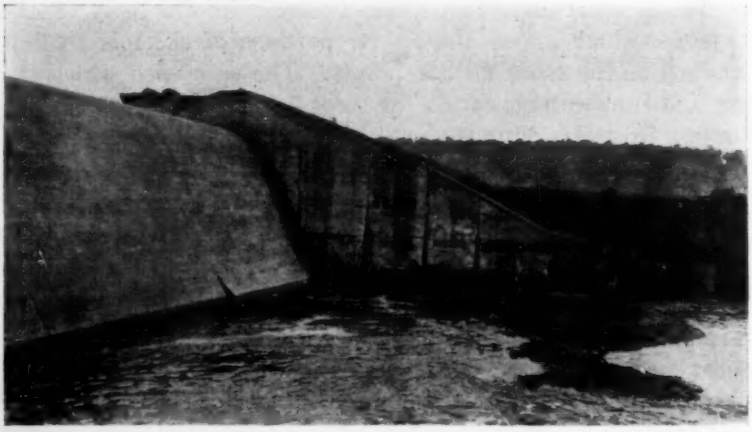

FIG. 21—DAM IN NORTHERN CLIMATE. NOTE GOOD CONDITION OF SPILLWAY IN CONTRAST WITH ABUTMENT WALL

FIG. 22—CRYSTAL SPRINGS DAM, CAL. A DRY TAMPED CONCRETE PLACED IN 1886-1888

sisting the weather much better than the layer immediately below. This lower layer is almost devoid of coarse aggregate for a considerable depth below the top. This dam was about 13 years old when this picture was taken.

Fig. 20 shows a 2-ft. bed of laitance resulting from placing concrete through 14 ft. of water. Fig. 21 shows a dam in a severe climate in which the concrete in the spillway was placed with extreme care, while in the abutment there is evidence of water gain and laitance with consequent seepage at the fill planes.

These illustrations could be multiplied indefinitely with each case showing some major or minor defect resulting from the manner in which the work was carried out. It is fitting to close this discussion with an example of concrete which is well preserved because it was well placed. Crystal Springs Dam, shown in Fig. 22, is such a structure. This dam was built between 1886 and 1888 by Herman Schussler, chief engineer of the Spring Valley Water Co., of San Francisco. It is a masterpiece of good construction using the dry tamped method. Every detail of preparing the materials, measuring the quantities (including the water), mixing, placing, ramming, and curing were carried out in accordance with carefully prepared instructions. It stands as a monument to Mr. Schussler and his careful methods of construction.

Readers are referred to the next paper and to discussion of both which follow it and are referred further to the JOURNAL *for Nov., 1931, (Vol. 28) for discussion which may develop. Such discussion should reach the Secretary by Oct. 1, 1931.*

More Lessons from Concrete Structures in Service*

BY RODERICK B. YOUNG†

Any public utility, railroad or government has such a considerable investment in concrete structures that their behavior in service is a question about which they must needs be concerned. Realizing this, the Hydro Electric Power Commission decided, some years ago, to systematically study the behavior of their many concrete structures, with a view to learning not only their existing condition, but their probable condition in years to come. The examinations thus made disclosed so many interesting points in connection with the behavior of concrete in service, that it was extended to include other concrete structures in different parts of Canada and the United States, until the number of inspections now made have reached a total of several hundred. This paper is an attempt to set down briefly some of the conclusions that have been reached as a result of these examinations.

Very few concrete structures are entirely free from disintegration of some kind or other, and their defects are usually so much more conspicuous than serious that they lead the casual observer to condemn concrete as a building material, forthwith and forever. Even the critical observer is apt to become despondent by the seeming prevalence of defective concrete, and some of our well-known engineers are still in this mental condition as a result of their examinations.

However, this is not a fair view to take of the behavior of concrete in service. While defective places can be found in most concrete structures, they are usually of very limited extent

*Presented at the 27th Annual Convention, A. C. I., Milwaukee, Feb. 24-26, 1931 as part of the work of Committee 801, Durability of Concrete, see p. 1037.

†Testing Engineer, Hydro Electric Power Commission of Ontario.

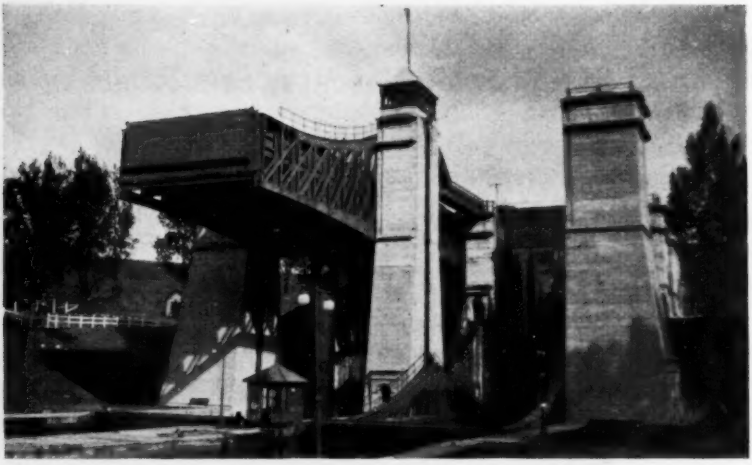

FIG. 1—LIFT LOCK AT PETERBOROUGH, ONTARIO, 26,000 CU. YD. OF ALMOST PERFECT CONCRETE WHICH HAS BEEN IN SERVICE SINCE 1904

and of minor importance. After any serious and wide-spread examination of concrete structures, one can hardly come to any other conclusion than that the greater part of the concrete in service today is in good shape and will remain so for many years to come.

One frequently finds old concrete structures in most excellent condition, resisting the destructive forces of nature, as well or better than any other material that could have been used. If anyone doubts the truth of this statement let him visit the Trenton Dam near Rome, N. Y. or the Hinckley Dam nearby, the Lift Locks at Peterborough, Ontario, the Crystal Lake Dam near San Francisco, Calif.[1] or the Thomson[2] and Pine River dams in Northern Minnesota, for these structures offer convincing proof that concrete when properly made is a durable material.

On the other hand, one occasionally meets with a structure in which the greater part of the concrete is disintegrating, but even in these cases it is the rare exception to find one so poorly made that there is not a considerable part of it in first-class shape. Even such a horrible case as that shown in Fig. 3 has its good

[1]References are listed at the end of this paper.—EDITOR

FIG. 2—SIDE WALL OF PETERBOROUGH LIFT LOCK, WHICH IS UNDER WATER PRESSURE. NOTE ALMOST PERFECT CONDITION OF CONCRETE AFTER 27 YEARS' EXPOSURE TO SEVERE NORTHERN CLIMATE

points, and I think I can safely say, after the examination of a great many concrete structures, that not one per cent can really be classed as failures in the sense that the concrete has deteriorated or will in the near future, deteriorate to such an extent that early replacement will be required.

In any extended examination of deteriorated concrete the observer is struck with the fact that there is a marked similarity in the appearance of many of the affected areas and in the manner

FIG. 3—EVEN SUCH A HORRIBLE EXAMPLE OF POOR CONCRETE AS THIS HAS AREAS WHICH ARE IN FIRST-CLASS CONDITION. THIS RETAINING WALL IS APPROXIMATELY 20 YEARS OLD

of their occurrence. One comes gradually to classifying them by type, and in the majority of cases finds, from the evidence offered by the concrete itself, that the circumstances surrounding the cases of a common type are similar.

By far the greater number of cases of deterioration are due to the segregation of the concrete mixture before or during its deposition. The author, in a previous paper[3] before the Institute, gave numerous examples of typical defects due to this cause and explained the manner in which they occurred. Briefly, it was shown there that the principal causes of segregation are the use of over-wet mixtures, improper methods of handling and placing, and over-manipulation of the deposited concrete.

The evils of excess water manifest themselves in water-gain and the formation of laitance at the top of "lifts" and in the accumulation of mortar and fine material in corners, at vertical joints, and under sloping forms. Improper handling and placing cause, not only the familiar honeycombed areas of gross segregation, but the even more dangerous sections of concrete that are not noticeably segregated but are sufficiently so as to be porous and permeable. Over-manipulation is frequently the result of an

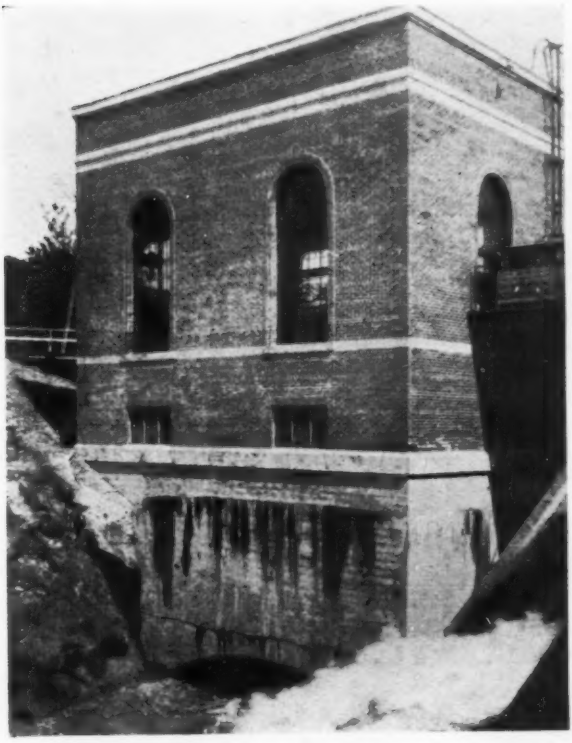

FIG. 4—DEFECTIVE HORIZONTAL JOINT CAUSED BY CARELESS CONSTRUCTION. CORROSION OF THE CONCRETE ADJACENT TO THE JOINT HAS NECESSITATED REPAIRS

attempt to obtain good surfaces with poorly proportioned and harsh-working concrete mixtures, by excessive puddling and spading of the surfaces. But whatever the cause of segregation, the result is failure of the affected concrete, if the exposure to which it is subsequently subjected is sufficiently severe.

If segregation is also the most common cause of deterioration, it is also the one for which there is the least excuse, and it may be well to point out here, as will be done later, that segregation is almost entirely preventable by a little ordinary care and forethought.

FIG. 5—DETERIORATION ADJACENT TO A VERTICAL JOINT. A POROUS CONCRETE MADE FROM PIT-RUN GRAVEL PLACED WET

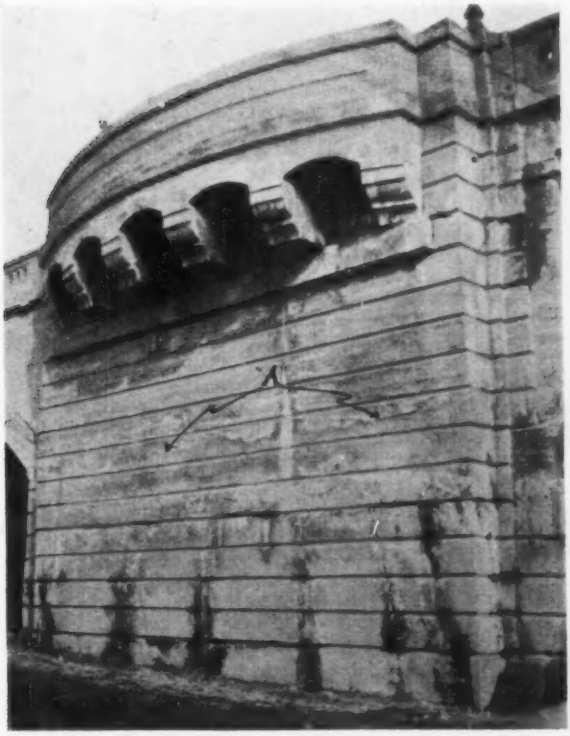

FIG. 6—POOR DRAINAGE NECESSITATED THE REPAIR OF THIS BRIDGE PIER AT "A." NOTE THE DETERIORATION OCCURRING ADJACENT TO LIME ENCRUSTATIONS

After segregation, probably the next most common type of deterioration is caused by joints, either vertical or horizontal, which are not water-tight. With these might also be classed cracks due to shrinkage or structural movements, through which water seeps. Where the concrete adjacent to the joint or crack is of poor quality, due to segregation or other causes, the deterioration may become serious. Where the concrete is good, the effect of the presence of water is likely to cause only an unsightly blemish and so the potential danger of the situation is overlooked. That there is a very real danger in the continued passage of water

FIG. 7—ANOTHER EXAMPLE OF THE DETERIORATION OF A BRIDGE PIER CAUSED BY LACK OF DRAINAGE. NOTE AGAIN THE PRESENCE OF LIME ENCRUSTATIONS AND THE PATCHING AT "A"

through concrete is evident if one realizes that practically all its cementitious material is water-soluble and may be removed by solution if enough water is available.[4] The presence of calcium carbonate deposits, sometimes in great quantity, wherever seepage occurs is proof, if other proof is needed, of this statement.

Trouble of this kind is particularly likely to occur in hydraulic structures such as dams and conduits, but is also commonly found is retaining walls and bridges. In the majority of hydraulic structures there is no other corrective except to make the joints water-tight, which can be done by exercising the greatest care in their construction, and by the use of waterstops where, for any reason, movement of the joint may occur. In the case of retaining walls and bridges, much may be done by water-proofing and drainage. Engineers designing reinforced concrete bridges should give a great deal of thought to these points for one finds many very fine structures which would not be in their present unsightly condition if they had been properly drained.

Another very frequent cause of deterioration, especially along the sea coasts, is the corrosion of the embedded reinforcing steel.

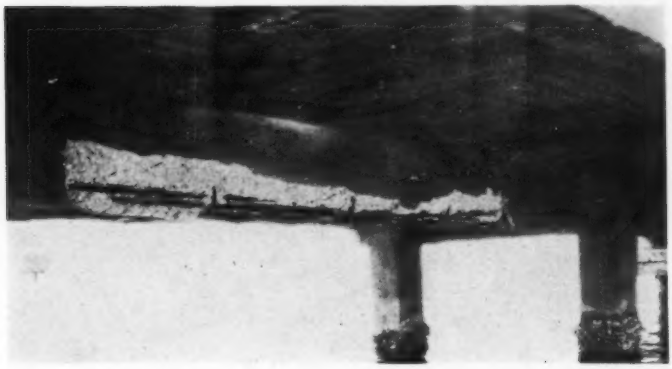

FIG. 8—ONLY 10 YEARS OLD, BUT THIS BRIDGE HAS HAD TO BE ABANDONED DUE TO THE PREVALENCE OF SIMILAR CONDITIONS

The oxides of iron, which form in the presence of moisture and oxygen from the corrosion of steel, occupy roughly two to three times the space of the original steel they replace, and consequently a reinforcing bar, if allowed to rust, will crack or spall the concrete surrounding it.

This type of deterioration is very prevalent along the sea coasts, although it is by no means confined to those localities. In the southern parts of the continent where frost action is absent, it is by far the most serious form of deterioration and the most common. It is serious because in many cases any considerable spalling of the concrete endangers the safety of the structure and may even cause its failure.

Since there seems to be no practical method of rust-proofing the reinforcement, the obvious remedy is to embed the bars in dense impermeable concrete to a depth sufficient to protect them from moisture and air. Seemingly this should not be difficult to do, as one can discover instances where as little as one-half inch of concrete or mortar gave complete protection to the steel. The present excellent condition of most of the concrete ships built during the war is proof of this, and other examples such as that illustrated in Fig. 9 are not uncommon.

However, even if the engineer designs his structure to provide sufficient embedment of the reinforcement and specifies and

FIG. 9—ONE-HALF-INCH OF DENSE, IMPERMEABLE CONCRETE HAS PROTECTED THIS STEEL FOR SIX YEARS

obtains a dense durable concrete with which to cover it, he has not done his complete duty until he designs his reinforced concrete members in such a way that the quality concrete that he has provided can be placed properly around the reinforcing steel. If the bars are so concentrated and spaced that it is impossible to get concrete around and through them without the use of excess water or over-manipulation, one can hardly blame the concrete or the workmanship for any deterioration that subsequently occurs. In the case illustrated in Fig. 9, a covering of one-half inch of the concrete had protected the steel for six years. The concrete here had the hardness and appearance of one that would test 3500 lb. per sq. in. or better, and apparently had been well cured. However, the beams made of this same concrete repeatedly show cracking along the line of the tension reinforcement, and as far as one could determine, the probable cause was the difficulty of properly placing the concrete in the bottom of the beam below and alongside of the steel.

Certain localities are blessed with very fine aggregates and in these, deterioration of the concrete due to unsound aggregate is practically non-existent. In other localities, not so blessed, cases of deterioration due to the failure of the aggregate are fairly common. The author has had the opportunity to observe con-

crete structures in several of both types of localities and while there is no question but that the quality of the aggregates has an important influence on the condition of the structures, unsoundness of the aggregate alone is seldom the primary cause of disintegration, although it is usually a contributory factor where other detrimental conditions exist.

This statement is probably more nearly true for the coarse aggregate than for the fine. In most of the cases that the author has examined where the coarse aggregate was unsound, it seemed probable that if the mortar surrounding the coarse aggregate had been of better quality, the unsound aggregate alone would not have been able to cause disintegration of the concrete. It is not at all uncommon to see evidence, such as in Fig. 13, where a great deal of unsound coarse aggregates has been used and still the concrete was generally in good condition. On the other hand, where unsound coarse aggregate is to blame for the disintegration of the concrete, the failure is usually distinctive and complete.

Unsound coarse aggregate may be protected by being surrounded by a durable mortar, but if the mortar itself is made up of unsound fine aggregate, the concrete is doomed. In such cases, the failure is a true disintegration and takes place relatively rapidly, usually manifesting itself within a very few years by a general deterioration and softening of the concrete.

There is a belief, in some quarters, that unsound cement is the cause of most of the deterioration of concrete, while others argue to the contrary. One occasionally meets with a clear-cut case of disintegration where all the evidence points to the cement as the cause, but these cases are rare. The author has made a careful examination of some dozens of deteriorated structures, the condition of which was blamed on the cement, and found therein so much evidence that other factors such as those already discussed, were mainly responsible for the present condition of these structures, that he has been forced to the conclusion, that whereas there may be cements which, although passing all the usual recognized tests, are still unstable in concrete, yet they do not have any important deleterious effect until other improper conditions are permitted to exist. The reasonable conclusion is, therefore, that if a cement meeting the present accepted standard

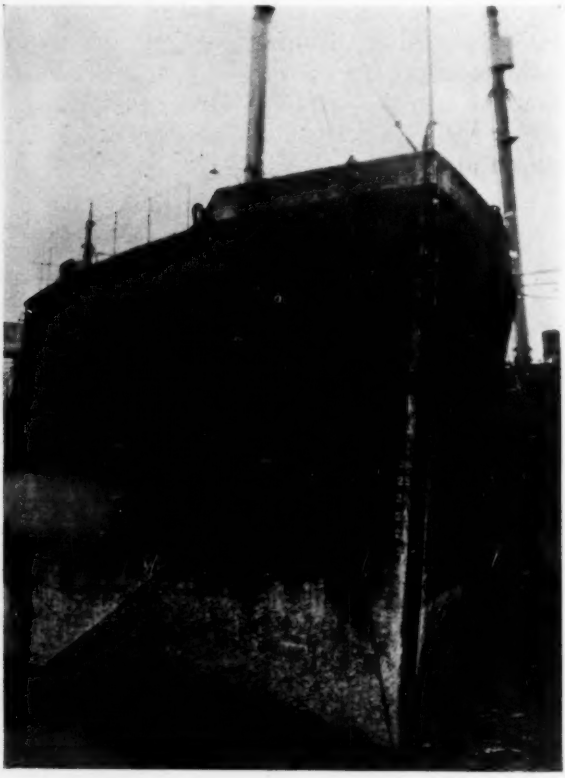

FIG. 10—BOW OF THE CONCRETE SHIP "FAITH" BUILT IN 1918. NO DETERIORATION HERE

specifications is used in a structure, future deterioration caused by the cement alone is extremely unlikely.

Any discussion of the behavior of concrete in service is hardly complete without reference to the agencies that bring about their deterioration. It should always be remembered that concrete structures are exposed to the same weathering conditions which, through the ages, have levelled whole mountain ranges and totally changed the aspect of continents. It should also be remembered that the same weathering agencies are proving destructive to stone masonry and to brickwork, and that only the complete protection of iron and steel structures save them from being

destroyed in a very short time. The following little couplet appearing in the *Engineering-News Record*[5] expresses this thought os aptly as to be worth repeating:

"Bricks will break and rocks will fall,
Paint will peel, and concrete spall,
Wood will rot, and steel will rust,
Ashes to ashes, and dust to dust."

Concrete has many enemies in nature, but by far the most important is the combined action of water and frost. One has only to make a tour from north to south, examining concrete along the way, to discover the part that frost plays in the deterioration of concrete. Below the frost belt, even the poorest concrete will give service for years without appreciable deterioration, and only when used in a reinforced concrete structure where corrosion of the embedded steel causes spalling, will its poor quality become conspicuous. One finds many structures in Florida and along the Gulf of Mexico that are ten or more years old and in first-class condition, which if north of the Ohio River would, in the same period, have required extensive repairs or replacement.

It should be remembered in dealing with the action of frost that it is not the freezing of the concrete itself that is harmful, but the freezing of water that is present in the concrete. Dry concrete, no matter what its quality, is not destroyed by alternate freezing and thawing, but let the pores of that concrete be filled with water to such an extent that no space is available to take care of the expansion that inevitably takes place when water changes to ice, and disruption must occur unless the concrete is strong enough to resist the large stresses set up. If one considers that concrete is relatively weak in tension, one sees the reason why, in making concrete resistant to frost action, impermeability is so much more important than strength.

It should also be remembered that while concrete may resist one freezing or several when saturated with water, yet the continued repetition of this action will in time destroy it. Further, disintegration due to frost proceeds from the surface inward and only a few degrees of frost are required to cause freezing of the contained moisture in the surface layer. It would seem, therefore, that the effects of frost should be more severe in those sections of the continent that have the greatest number of alternate

FIG. 11—DETAIL OF BOW OF S. S. "FAITH." NOTE FREEDOM FROM STEEL CORROSION, ALTHOUGH SOME OF THE REINFORCEMENT IS ONLY EMBEDDED ONE-HALF INCH

freezings and thawings, and while this is not subject to statistical proof, it seems to be borne out in a general way by observation. It certainly is a fact that as soon as one enters those sections having more than a very few annual frosts, the evidence of frost action is almost as common and as conspicuous as in districts further north, so that it behooves the engineer in those sections having mild winters to remember that his concrete structures are subject to as severe, and possibly more severe exposure than those in more rigorous climates.

If frost is not a destructive agent except in the presence of water, then it might truthfully be said that water is concrete's worst enemy. As already mentioned, water alone will destroy concrete through its solvent action, but more important, water is the medium through which most of the other enemies of concrete carry on their attack. Sea water, sulphate-bearing waters, and bog waters are merely waters carrying impurities that render their destructive action more severe, and all act through the intimate contact that the water has with the concrete through absorption in its pores.

Perhaps the author is inclined to over-rate the importance of water as a destructive agent due to his long contact with hydraulic structures, but it is also possible that others, differently situated and not having had the same chance to observe the

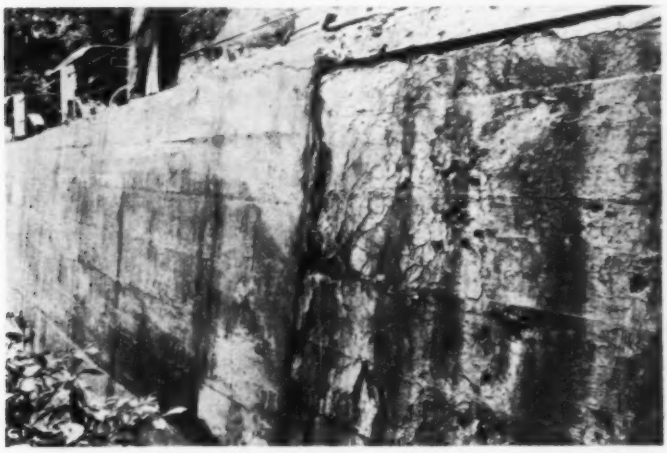

FIG. 12—UNSOUND AGGREGATE CAUSED THE CONDITION OF THE CONCRETE AT THE RIGHT. THE CONCRETE AT THE LEFT IS SIMILAR IN ALL RESPECTS, EXCEPT THAT A DIFFERENT COARSE AGGREGATE WAS USED

destructive effects of water, under-rate its possibilities instead.

Research tells us that, given the opportunity, any water will, in time, completely remove the binding material which is formed in concrete by the hydration of cement[4,6,7] and a few cases of the kind have been reported in the technical press[6,8,9,10,11]. However, for the most part, engineers are inclined to think of such action as a remote possibility, but in this, they are wrong, for it is a quite common occurrence around hydraulic structures, although its true nature is often obscured by being combined with frost action.

Mention has already been made of the solvent action of water adjacent to leaking joints or cracks, but it is by no means confined to these places. Porous concrete, where totally submerged is water, will have the cementitious material dissolved therefrom in a few years, even when the water in contact with it is hard. The author has had three cases of this kind requiring major repairs, occur in his work in as many years, besides two others where the solvent action of water was the primary destructive agent, but was assisted by the surface action of frost.

FIG. 13—SPALLING DUE TO UNSOUND COARSE AGGREGATE. THE EFFECT OF THE UNSOUND AGGREGATE IS CONFINED TO THE SURFACES

Another manifestation of the solvent action of water is regularly found wherever concrete has been in contact with soft pure waters for any length of time. In such cases, the water dissolves the surface coating of cement mortar, exposing the underlying aggregate. This action takes place relatively rapidly at first, until the aggregate has been exposed, after which the action becomes very slow for then the only cement in contact with the water is that between the aggregates. The author has examined concrete structures less than two years old that have been etched in this way, and others from ten to thirty years old that had a deeper etch, but still no unravelling of the affected surfaces. In hard water this etching action is very slow.

Examples of the solvent action of water may often be found where drainage conditions are such that rain water runs over the surface of concrete. The same phenomenon will be found also on the tops of cornices, handrails, sills, and the treads of steps, and along the lower edges of the same cornices, handrails and sills, where water collects during rains.

None of these surface manifestations of the corrosive action of water are serious, but give a quantity of that same water a

chance to penetrate the concrete and the results may be very dangerous.

A study of the characteristics of those waters that have proved most corrosive to concrete, reveals the interesting fact that, whereas the hydration products of cement are soluble in any water, those that are most destructive are relatively pure waters carrying so little CaO in solution that they are lime hungry and having an acid reaction as indicated by a hydrogen-ion concentration below 7.00. These observations have been confirmed by investigations recently reported in Germany.[12]

The addition of certain salts to a water will increase its destructive properties. Sea water and the sulphate-bearing waters of the west are both cases in point, and in both, the salts involved are principally the sulphates of magnesium, sodium and calcium. The action of these compounds on the concrete appears to be both chemical and mechanical, the chemical being partly a corrosive action and partly an interference with the normal processes of hydration,[6,13] the mechanical due to the disruptive effects of the by-products of the chemical reactions, which forming compounds within the cementing matrix of the concrete require more space than the materials they replace.

A great many natural waters, both ground and river, contain one or all of the sulphate salts in solution, but unless the quantity is considerable, their presence is unimportant. However, in some parts of both western Canada and the United States, there are localities where the ground waters contain dangerous concentrations of these sulphate salts and where sulphate action becomes a matter of major importance to engineers, but generally speaking, sulphate determination is a local, rather than a continent-wide problem. On the other hand, it is found elsewhere occasionally and the engineer asked to diagnose a case of disintegrated concrete and prescribe for its treatment should not overlook that fact. Its manifestations are usually, but not always, distinctive and may easily be obscured by frost action. Where there is any suspicion of sulphate action, a chemical analysis of the disintegrated concrete will show whether or not one's suspicions are justified.[14]

All sea water structures are liable to sulphate action due to the presence of these salts in the ocean. However, while the

FIG. 14—A POROUS CONCRETE 20 YEARS OLD WHICH WOULD HAVE RAPIDLY DISINTEGRATED IF SUBJECTED TO FROST. MADE OF FINELY-GRADED SEA SAND AND SHELLS

author's observations of sea water structures have been limited, it has led him to question whether the destructive tendencies of sea water were due to the salts it contains as much as to the fact that it was water. One can duplicate in the harbors of the Great Lakes all of the types of deterioration that one sees on the North Atlantic seaboard. Along the southern coasts below the range of frost, there is little evidence of chemical deterioration of the concrete, other than the surface etching met with in fresh water where it is of a corrosive type. There is a great deal of spalling due to corrosion of the embedded steel, and while this type of action will naturally be more severe in the presence of salty moist air, it is by no means confined to the seacoast, but is quite common elsewhere. There is the further fact that sea water does not contain high concentrations of the sulphate salts. The author, therefore, is inclined to believe that most of the deterioration of concrete in sea water is due to the same factors which cause it elsewhere and not, as usually claimed, to the presence of sulphates.

We have now considered both the effects brought about by the deterioration of concrete and the principal agencies that have acted to bring these effects into being. We have also considered,

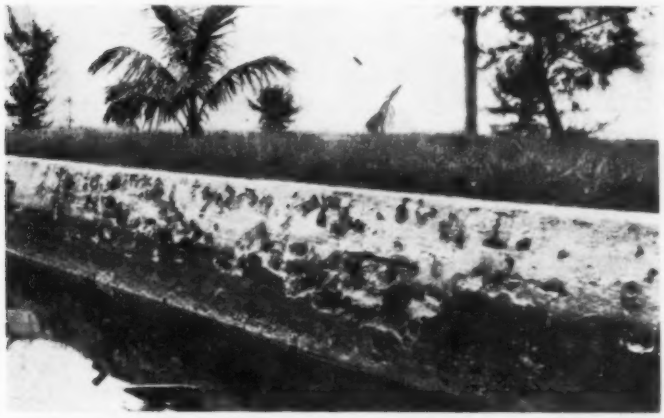

FIG. 15—ANOTHER SOUTHERN WALL OF VERY POOR CONCRETE, WHICH EXCEPT FOR LOCAL SPALLING DUE TO AGGREGATE, IS IN FAIR SHAPE

though rather briefly, some of the faults of workmanship that usually accompany deterioration. Can we not now deduce from the information thus obtained, what property of the concrete renders it susceptible to attack?

The answer to this is neither difficult nor new; the author pointed it out some years back,[15] and others have done likewise. The fundamental condition which is common to almost every disintegrated concrete is that it is porous in the sense that it is absorptive or permeable to water. Prevent the penetration of water into concrete and at once it becomes a building material highly resistant to all ordinary destructive agencies. Even in the case of those waters which will destroy any concrete in time, such as concentrated sulphate waters, the rate of deterioration is greatly reduced where it is confined entirely to the exposed surfaces, as it must be if the concrete is impermeable.

If one accepts this conclusion, as one almost must after a critical review of the evidence offered by concrete everywhere, then the problem of durable concrete becomes the problem of making it dense and non-porous, or speaking in terms of measureable properties, impermeable and non-absorptive. Reduced to these terms, the problem is theoretically easy of solution for the fundamental factors in the making of a dense, water-tight, high-

strength concrete have long been known and are generally well understood. Practically, the problem is more difficult, for the degree of skill and care used in handling and placing concrete is of paramount importance in making it durable, and proper workmanship in these particulars is not always easy to obtain.

No attempt will be made here to consider the factors necessary to produce a dense, impermeable and strong concrete. If the reader is not already familiar with them he has only to consult the recent technical literature[16,17] to find them discussed in full, but it might be useful for the author to consider briefly here a few points that his observations have led him to believe are important in any concrete which is to be subjected to severe exposures.

One of the conditions that frequently give difficulty is the use of harsh, unworkable mixtures. A concrete mixture deficient in mortar is not only more likely to segregate in handling, but even if this is prevented, it requires a great deal of spading to give presentable surfaces, which, in turn, causes scaling. Mixtures of this type are also inherently porous, because their harshness is usually due to a lack of mortar or to a mortar which is itself harsh from a deficiency in the grading of the fine aggregate. In addition to these drawbacks, a harsh mixture is more apt to segregate in handling, and because of its lack of workability, there is much more chance that some well-intentioned individual will attempt to overcome its deficiencies by the addition of water.

Another frequent cause of disintegration is the use of over-lean mixtures. Cement plays a dual role in concrete; in combination with water, it forms the glue that binds the aggregates together, but it and its products of hydration also fill and seal the smaller spaces in the aggregate mass. Any reduction in cement content beyond a certain amount is accompanied by an increase in porosity until a point is reached where, if the exposure is severe, disintegration is almost inevitable.

Instances of disintegration due to lack of cement are by no means uncommon and several have been reported to the Institute. The matter is one that every engineer would do well to remember when he specifies concrete in terms of its compressive strength. With the modern cements, it is now taking less cement to obtain concrete of a given 28-day compressive strength than it did eight or ten years ago, and the result is that quality as measured by

FIG. 16—POCKETS OF SEGREGATED CONCRETE FROM WHICH CEMENT WAS TOTALLY REMOVED BY SOLUTION. NOTE POSITION OF WATER LINE AT "A" AND SLIGHT ETCHING OF SURFACE, WHERE WATER IN CONTACT WITH IT IS HARD. COMPARE WITH FIG. 18

strength is not the same today as then. As an example, take the experience of the Hydro Electric Power Commission of Ontario. In 1920 the Commission built a hydro-electric plant and used approximately seven sacks of cement per cu. yd. to produce a concrete testing 2500 lb. per sq. in. at 28 days. In 1930 they built another plant a few miles away on the same river with aggregate and cement from the same source and using five and three-quarter sacks per cu. yd. obtained concrete testing 3500 lb. per sq. in. at 28 days. Concrete of the same strength as that made in 1920 could have been produced with about four and one-quarter sacks per cu. yd., but the latter, while as strong, would not have been as impermeable, and hence as durable and so in this case the governing feature in the choice of the cement content was durability and not strength.

Strength can never safely be taken as a measure of impermeability in a concrete, for while it is true that for a given set of conditions, the greater the strength of a concrete the less its permeability, it is not true that a certain degree of permeability will exist in all concretes of the same strength regardless of the

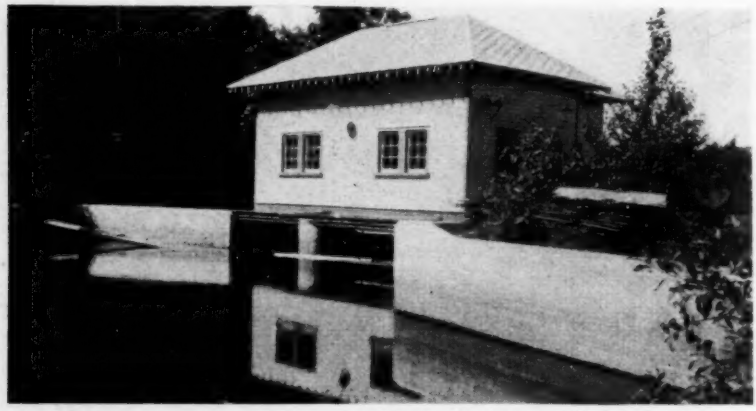

FIG. 17—THE FIRST CONCRETE PUT IN UNDER WATER-CEMENT RATIO CONTROL, BUILT IN 1919

aggregate, the cement content, or the treatment that it has received. A concrete of today is probably more permeable and hence less durable than concrete of equal strength made ten years ago, and yesterday's standards of quality no longer apply to today's concrete. It is the author's opinion that the widespread adoption of the strength specification for concrete is creating a situation dangerous to the industry, for the same engineers who are now adopting the newer forms of specification are still using the old standards of strength as a measure of quality, in the belief that in meeting these they are assured of a durable weather-resistant concrete.

Segregation of every form is extremely dangerous to the permanence of concrete. Some of the consequences of segregation have already been mentioned in the beginning of this paper and the practices which most frequently cause segregation were touched upon. But, whether or not segregation is the result of excess water, improper handling, a poorly designed mixture, or over-manipulation, the fact remains that practically all segregation is easily prevented by the exercise of ordinary care and forethought, and there is no excuse for any architect, engineer or contractor to tolerate its presence in any concrete work for which he is responsible. He has a right to demand and expect

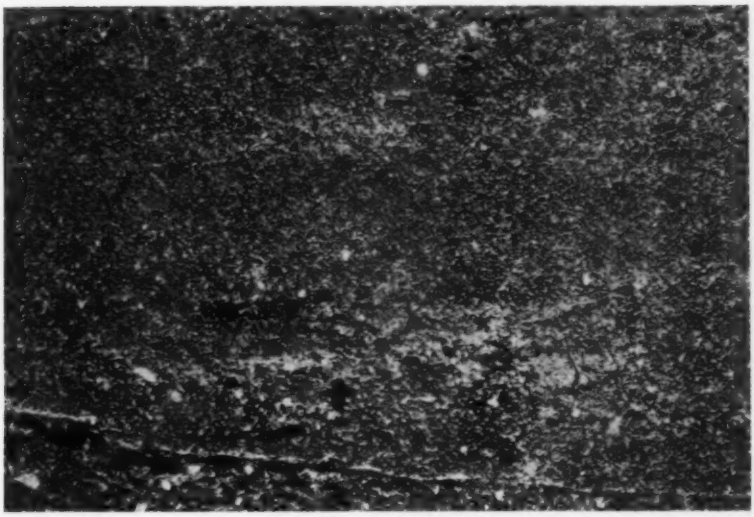

FIG. 18—CLOSE-UP OF A PART OF THE CONCRETE SHOWN IN FIG. 17 WHICH HAS BEEN ETCHED BY BEING IN CONTACT WITH A CORROSIVE WATER

good workmanship in these particulars for it costs no more to handle and place concrete without segregation than with, particularly if the effect of segregation on the cost of finishing is taken into account.

Many a concrete job falls short of perfection because of lack of the proper kind of supervision. There has to be on the job some individual with a sound knowledge of concrete armed with the proper authority, whose duty it is to see that the quality of the materials, standards of workmanship, and the after-treatment of the concrete are as they should be. The success of those outstanding cases of durable concrete mentioned in an earlier paragraph was due in no small degree to the fact that such a man was connected with the job. The Petersborough Lift Locks had Walter J. Francis; the Crystal Lake Dam, Herman Schussler; the Thomson Dam, H. C. Ash, and so on, and they are enduring monuments to these men.

Supervision of a concrete job has to be intimate and continuous to be successful. It is not enough to make a daily visit to a job as is the too common practice of many architects and engineers.

FIG. 19—SCALING AND DISINTEGRATION DUE TO HARSH WORKING CONCRETE MIXTURES AND THE CONDITIONS ARISING THEREFROM

Someone should be present immediately before and during the placing of any important concrete. Such supervision adds but little to the cost of a structure and is cheap insurance to pay for a job that will be free from future trouble. And it is the common experience of those dealing with competent inspectors that in many indirect ways they effect economies of operation that more than offset the cost of their services.

Summing up, the author has arrived at the following conclusions as a result of his experience with concrete good, bad and indifferent:

(1) Generally speaking, concrete structures are satisfactorily performing the functions for which they were built.

(2) While few concrete structures are wholly free from deterioration, the excellent condition of the greater part of even those which would be classed as examples of poor concrete, and the outstandingly good condition of others 20 or more years old, are proof that concrete is and can be made durable.

(3) Most cases of deterioration can be classified into a few types to which definite causes can be assigned.

(4) Most of the defective concrete is due to faults of workman-

ship, the use of excess water, and other causes that are strictly preventable by the exercise of reasonable care and supervision during construction.

(5) Faulty construction joints are very prevalent and under certain circumstances may start dangerous deterioration.

(6) Unsound aggregate can cause serious disintegration, but trouble of this kind is not general and usually does not become a factor in destroying concrete unless the concrete is otherwise unsatisfactory.

(7) Cement is seldom a primary cause of concrete deterioration.

(8) The principal naturally occurring destructive agents affecting concrete are frost, water, and the corrosion of embedded steel.

(9) Water, if allowed to penetrate concrete may, and often does, totally destroy it due to its solvent action on the cementitous binder.

(10) Fundamentally, most concrete deterioration is due to its being porous.

(11) The best recipe for durable concrete is to make it so dense and impermeable that water cannot enter.

(12) Harsh, unworkable concretes are prone to deteriorate.

(13) Lean concretes, no matter how strong, are not durable.

(14) Intelligent and constant supervision of concrete during construction is necessary to insure durable concrete.

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DISCUSSION BY L. W. WALTER*

IN THE papers presented by Mr. McMillan and Mr. Young, the authors have brought to us some impressive lessons arising out of their experience in work directed along the lines of the activities of Committee 801. Coming as they do from men who have made it their business to acquaint themselves with the performance of concrete structures of various types under different conditions of exposure, and whose business it is to know how to overcome the deficiencies which they have observed, and which their investigations have revealed, these papers commend themselves to the careful study of all those who have been less favored by opportunity and experience.

It is brought out that, of the factors affecting the durability of concrete, the one of most concern is the action of frost on saturated concrete. It follows from this that the most important requirement of concrete, in the interest of durability, is watertightness. This requirement is essential, not only in freezing climates, but in concrete exposed to corrosive waters, and in reinforced concrete structures in or very near sea-water.

It has also been my privilege to examine many structures with which I have been familiar from a standpoint of construction and conditions of exposure, and to have accompanied the authors of these papers in a survey of many structures in a climatic range extending from Key West, where frost is unknown, through the northern part of the United States and southern Canada,

*Inspecting Engineer, Erie Railroad Co., Jersey City, N. J., Member Committee 801.

where frequent cycles of freezing and thawing have their telling effect on concrete of inferior quality, and into the north woods where a diminishing number of freezing and thawing cycles seem less severe in their toll, even though the winter temperatures are low. My conclusions from these examinations are in agreement with those of the authors of the papers presented.

There is one important matter brought out in Mr. Young's paper which I particularly desire to emphasize, namely, that strength alone is not a dependable measure of water-tightness or durability.

In the design of concrete to meet the fundamental requirements for strength, durability and economy, too little consideration is being given to the fact that, as measured by 28-day test results, present day cements carry higher strength-giving quality to the concrete than was characteristic of cements of earlier periods, but do not produce correspondingly higher ultimate water-tightness when used in like proportions.

The gradual but constant stepping up from year to year in strength-giving quality of cement, as determined by the 28-day tests, without its contributing, in a corresponding degree, to higher ultimate water-tightness of concrete, calls for extreme caution in the selection of a particular class of concrete, classified on a strength basis.

Unfortunately, many users of concrete are overlooking the basic principle of the water-cement ratio law, and, in trade practice, are depending upon strength as the sole measure of quality. With present day cements, it is possible to get relatively high 28-day strength of concrete with mixtures lean in cement and with a high water-cement ratio. Such mixtures are too porous to withstand unfavorable exposure.

In order to stop this trend in trade practice, and to safeguard against the use of these porous mixtures, it seems necessary to indicate in our specifications (separately for each class) not only the maximum allowable amount of water per bag of cement, but also the minimum allowable amount of cement per yard of concrete.

Readers are referred to the JOURNAL *for Nov. 1931, (Vol. 28) for further discussion of the two preceding papers which may develop. Such discussion should reach the Secretary by Oct. 1, 1931.*

The Permeability of Gravel Concrete*

BY PAUL T. NORTON, JR.† AND DAN H. PLETTA‡

INTRODUCTION

The research project reported in this paper was begun three years ago in the Mechanics Department at the University of Wisconsin in the hope of determining the relationship between permeability and water-cement ratio, and also the relationship between permeability and such other properties as strength, consistency, absorption, cement-voids ratio and grading of aggregate.

A number of permeability tests had previously been made in this laboratory. In none of these earlier tests was the water-cement ratio computed, although F. R. McMillan has figured the water-cement ratio for the concretes reported in University of Wisconsin Bulletin 1245 (1923) and has plotted the flow of water against these values.

The data used in establishing the results of these observations were obtained from a series of tests repeated five times in order to aid in securing accurate averages. The program included the making and testing of 34 different mixes, with each of which three or four different amounts of water were used, ranging from that required for normal consistency to 35 per cent more than that amount. The mixes were designed to cover the range from those suggested by the Fuller-Thompson curve to others which were much over-sanded. A complete series of 34 mixes was made and the series repeated five times in order to eliminate as much as possible such things as the aging of cement, the varying relative humidity, the change in temperature, the curing condition of the

*Presented by Dan H. Pletta at the 27th Annual Convention A. C. I., Milwakee, Feb. 24-26, 1931.

†Professor of Industrial Engineering, Virginia Polytechnic Institute, Blacksburg, Va.

‡Assistant Professor of Civil Engineering, University of South Dakota, Vermillion, S. D.

At the time these tests were made Mr. Norton was Assistant Professor of Mechanics and Mr. Pletta was Instructor in Mechanics at the University of Wisconsin.

specimens, the personal equation, etc. With each permeability specimen made from a given batch, two 6 x 12-in. cylinders were molded. One of these was used to obtain the compressive strength of the concrete, and the other for absorption testing. Nearly 2000 specimens were made and tested.

This research project was made possible through the research fund of the Mechanics Department of the University of Wisconsin. The authors are grateful to the institution with which they were formerly connected for the opportunity of carrying on this work and to Prof. M. O. Withey for his careful supervision of the tests and helpful suggestions in the writing of this paper. The authors also wish to thank M. E. Basford, Azmi Jemil, Robert Greiling, Leo Janicki, M. O. Scott and the others who assisted in the tests, and also the Atlas Portland Cement Co., the Lehigh Portland Cement Co., and the Universal Portland Cement Co. for their donations of the cement.

MATERIALS

Cement—The cement used in these tests was a mixture of equal parts of Universal, Lehigh and Atlas portland cement. Twelve barrels of each were mixed and stored in bulk in a large galvanized iron bin, which was made as air tight as possible by having the seams calked with tar and the door edged with felt. About 20 lb. of each brand was removed before the mixing and used for testing the individual brands and a like amount of the mixture set aside for a similar purpose.

The results of these tests are shown in Tables 1 and 2. Table 1, showing the chemical analysis of the individual cements, represents the tests of the respective manufacturers. Table 2 outlines the physical properties of each of the cements and of their mixture as determined at the laboratories of the manufacturers and the University of Wisconsin testing laboratory. The tensile and compressive test specimens were made, stored and tested according to A. S. T. M. specifications. The loose weight per cubic foot of cement was assumed to be 94 lb.

Sand—Mixes "A" to "a" inclusive, see Table 6, were made of Janesville sand, and "b" to "k" inclusive of University sand. Janesville sand is about two-thirds quartz and one-third dolomite; University sand is almost entirely quartz. Tables 3 and 4 show

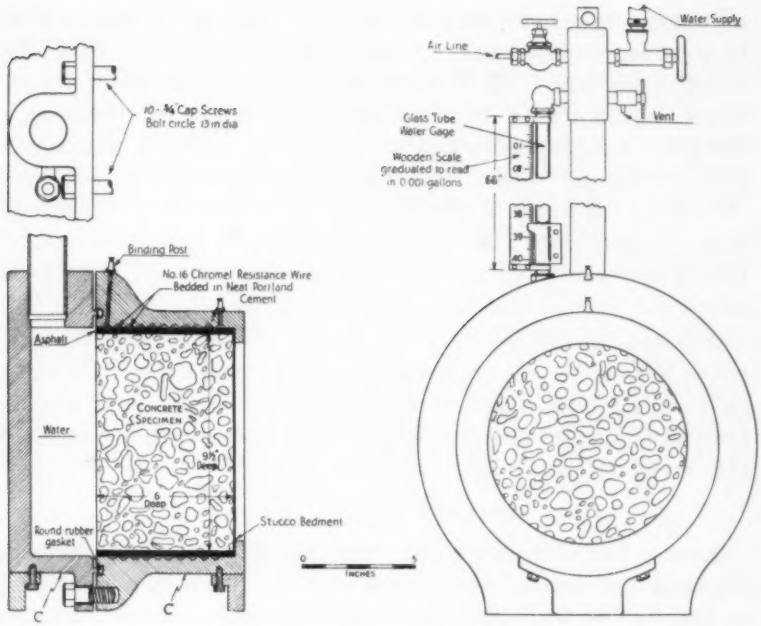

FIG. 1—APPARATUS FOR TESTING THE PERMEABILITY OF CONCRETE TO WATER

the physical properties of the two fine aggregates. All of the sand was screened through a ¼-in. sieve before it was tested or used.

Gravel—As the gravel was received it was screened into three sizes: ¼ to ⅜, ⅜ to ¾ and ¾ to 1½ in. The specific gravity and absorption of the three sizes varied somewhat, and since the individual sizes were combined to make the five different coarse aggregates used, the specific weights, specific gravities and absorptions also differed. This information is shown in Table 5. All of the material was Janesville gravel with the exception of the largest size used in the "Z" and "a" mixes. This was obtained from a gravel pit near Madison to reduce expense.

Mixed Aggregate—The sand and gravel were combined into 34 different mixes and the characteristics and proportions of materials in each are shown in Table 6.

Preparation of Materials—The sand was air dried before it was used by spreading it on the floor of the testing laboratory and

raking it occasionally for a day or two. The gravel was air dried in separate storage bins. About four hours before mixing the moisture content both of the sand and of the individual sizes of coarse aggregate to be used was determined by weighing a 500-gram sample, heating it in an oven to constant weight and then weighing it again. This information was used to determine the amount of water to be added to a particular batch so that the water-cement ratio would remain constant for individual batches throughout the series of tests. The temperature of the mixing water was kept at approximately 70 deg. F.

Weighing the Materials—The cement and aggregates for each batch were weighed on a scale sensitive to 0.05 lb. and the water on a scale sensitive to 0.01 lb. After the cement, sand and the individual sizes of coarse aggregate had been weighed separately they were weighed collectively for a check.

MAKING THE SPECIMENS

Mixing the Materials—After the materials had been weighed the sand and cement were placed on a metal mixing tray about 3 ft. 8 in. by 5 ft. 6 in., the surface of which had just been moistened. The cement and sand were first mixed to a uniform color by two men, working from opposite sides of the tray, turning the batch over twice with square pointed shovels. The coarse aggregate was then added and the mixing repeated. The water was poured into a crater formed in the aggregate and the material forming the crater was worked in toward the center. After the batch had been allowed to stand for a half minute it was mixed by turning over fourteen times.

Slump and Flow Tests—The slump and flow tests were made for each batch 10 minutes after completion of the mixing. There was a twofold purpose in the delay; it allowed the aggregate, which varied in moisture content from time to time, to absorb enough moisture so that the consistency remained almost constant for the same batches later in the series and it provided ample time to weigh materials for another batch.

Setting Up and Filling the Molds—The molds for the 6 x 12-in. cylinders used for the strength and absorption tests were set up on leveled steel plates. The molds for the permeability specimens were made of cylindrical metal sides with wooden bottoms

that had been thoroughly soaked in oil. The molds were oiled each time before they were filled.

Each batch of concrete was placed in the three molds as soon as possible after the slump and flow tests had been made. The 6 x 12-in. cylinders were filled one-third full, then tamped 25 times with a $\frac{5}{8}$-in. rod, then refilled another third, etc., and the top finally finished with a trowel. A metal plate was used as a cover to prevent evaporation. The permeability mold was filled half full and tamped 25 times, then filled completely and re-tamped, and the mold leveled off with a tamping rod. These molds were covered with wet cement sacks to retard drying.

Stripping the Molds—The molds were removed after 24 hr. The outer film of concrete on the top and bottom of the permeability specimen was removed with a wire brush and one of the other cylinders, later to be used for the absorption test, was subjected to a similar treatment on all surfaces. The other specimen was used for the strength test. The marks identifying the batches were painted directly on the specimens.

Curing the Specimens—As soon as the molds had been stripped and the specimens painted they were placed in a moist closet where they remained until 28 days old. Not more than eight batches were made at any one time, for the permeability apparatus was designed to test a maximum of eight specimens. The permeability test ran for at least 50 hr. and thus the frequency with which the eight batches could be made was also controlled.

APPARATUS

Permeability Apparatus—The apparatus for measuring the flow of water into the permeability specimens is shown in Fig. 1. The smallest divisions on the scale represent 0.001 gal., and, by use of the sliding target, readings may be interpolated to 0.0001 gal., although in this test such precision was adhered to only when reading the dummy, the readings for the test specimens being made to 0.0005 gal. The coil of high resistance wire was bedded in portland cement mortar which was mixed quite wet and cured for several days in the moist closet. The coil was used to heat the casting.

The air pressure system included two reservoirs, distribution pipe, flexible copper connecting tubes, a pressure gage and the necessary needle valves. The reservoirs were of relatively large

capacity when compared to the distributing pipe and so insured an almost constant pressure during the run.

The dummy consisted of a test unit similar to those used for the actual testing with the exception that the dummy specimen was cast on the outside of an iron plate and this bolted to a casting (c). The volume of water in the casting was the same as in the regular test units.

A wet and dry bulb thermometer and an electric fan for directing a current of air against the wick of the wet bulb were a part of the apparatus.

Heater for Absorption Specimens—The absorption cylinders were dried in a double-walled gas heater that was insulated on the top and sides with an asbestos covering. A solution of glycerine and water, mixed in such proportions that it boiled at about 220 to 240 deg. F., filled the space between the walls. The heater was large enough to dry 48 cylinders at one time.

TESTING

Length of Curing Period—Specimens were ordinarily removed from the moist closet at an age of 28 days. The permeability specimens of the first few lots were removed three or four days earlier with the expectation that they would be ready for testing on the 28th day but this was found to be impossible, and for the balance of the test specimens of all three types were removed at an age of 28 days, except for six lots which were removed at 27 days, 11 lots at 29 days and one lot at 30 days.

Compression Cylinders—Compression cylinders were broken on a 200,000-lb. testing machine the day they were removed from the moist closet. The top of the cylinders as molded was capped with neat gypsum plaster and the bottom also similarly capped in the few cases where an examination showed that this surface was not plane.

Absorption Cylinders—When the absorption cylinders were removed from the moist closet, they were first cleaned with a fiber brush, and then weighed to 0.01 lb. and left to accumulate until there was room in the heater. After they had been dried to constant weight they were immersed in water at room temperature and weighed after ½, 6, 24 and 48 hr. They were then capped on both ends and broken the same day. The weight after 48 hours in water was approximately the same as when first re-

moved from the moist closet so that the compression and absorption cylinders contained about the same amount of water when broken.

Permeability Specimens—With the exceptions noted in the first paragraph of this section permeability specimens were removed from the moist closet at an age of 28 days. They were immediately brushed to remove any loose material and weighed in air and in water to secure data from which the density of the concrete could be calculated. One coat of an asphalt priming paint was applied to the cylindrical surface to aid in securing a watertight bond. It was found that the surface of the specimen was dry enough for the priming coat after remaining in the dry air of the laboratory for about three days and that the priming coat required about 24 hr. to harden.

The first operation in the sealing process was to place the casting in a horizontal position with the circular shelf that supported the outer face of the specimen on the bottom. A small amount of neat gypsum plaster was then spread on this shelf and the specimen immediately placed and centered in the casting. The plaster bed prevented the molten asphalt from escaping during the pouring and supported the specimen rigidly in the casting when the air pressure was applied. Specimens were so placed in the casting that the flow of water was from the bottom to the top as originally molded.

After the plaster bed had dried for at least a half hour the casting was heated by passing an electric current through the resistence coil for three to five minutes. This was done for two reasons; first, to prevent the molten asphalt from being chilled before it could completely fill the space around the specimen and, second, to improve the seal by compressing the asphalt as the casting shrank upon cooling. Crystal Steep Roofing asphalt was used.

After the asphalt was poured, the casting with the specimen sealed within it was bolted to the other part of apparatus, the soft rubber gasket having first been put in place. The permeability tube was then filled with water and the copper tubing carrying the air pressure to the top of each water column attached. After the air had been applied the valves between the air reservoirs and the rest of the apparatus were closed to determine

whether there were air leaks in the tubing or connections. The actual testing was begun after any such leaks had been stopped and the air valves opened. Readings were then taken of the height of the water in the permeability tubes, of the height of the water in the dummy unit, of the air pressure and of the temperatures as read from a wet and dry bulb thermometer. All of the readings were taken every time the height of the water in the permeability tubes was read.

Ordinarily readings were taken and the face of each specimen examined at intervals of one hour or so for the first few hours and afterwards at greater intervals. In general at least three readings were taken each day during the 50-hr. test period.

Changes in air pressure and in room temperature produced changes in the height of the water column. In order to correct for such changes the dummy readings were employed. It was found, however, that the corrections for such changes were necessary only in the less permeable specimens.

The room temperature and relative humidity were not considered in calculating the data, for they appeared to have no material effect on the flow of water through the specimen, although they probably had some effect on the appearance of the face where there was enough water flowing through to make the surface appear slightly damp.

The pressure on the top of the water column was maintained as nearly as possible at 40 lb. per sq. in. except in some of the later tests where 100 lb. was used. In most cases it varied only slightly during the run. The increase in pressure on the specimen due to the height of water in the tube was not considered, for the differences in water flow due to such small changes in pressure are much less than the difference regularly found between two specimens of the same mix.

Untreated city water was used, it being considered that the test period was too short to permit clogging of the voids in the concrete by sediment in the water or by bacterial action. It should be noted that the apparatus was completely drained of water between runs and a fresh supply used with each set of specimens.

While no attempt was made to measure the water flowing from the concrete, the face of each specimen was carefully examined at

each reading and its condition noted on the data card. A defective seal could be detected by the appearance of water at the edge of the specimen. In such cases a notation was made on the card and the specimen rerun at the first opportunity. Some of the specimens were plainly defective and such specimens were not considered in calculating the data.

At the end of the test period the air valve leading to the reservoirs was closed and the casting containing the specimen removed from the apparatus. The casting was then turned so that the specimen would drop out when the asphalt was melted by passing an electric current through the heating coil imbedded in the casting. The inside of the casting was scraped to remove the asphalt and the gypsum that did not come out with the specimen and it was then ready for the next specimen.

COMPUTATIONS

Permeability—The data on the flow of water was plotted on graph paper, the flow being plotted against time, and the resultant curve corrected when necessary from readings of the dummy. The 20, 40 and 50-hr. flow was read from the curve and listed in a table. The flow for the 20 to 50 and 40 to 50-hr. intervals was thus obtained, the units being gal. per sq. ft. per hr. The values are given in Table 8. Whenever the test results for any one specimen did not conform more or less to the average of other specimens of the same mix, the data were discarded and the specimen rerun at a later time. In a few instances so much difficulty was experienced in obtaining data that only three values were used in the average, but this was true in only about 5 per cent of the cases. About 60 per cent of the results are the averages for five values and 35 per cent the average of four values.

Density—In computing the density of the individual batches the weights of the permeability specimen in air and in water were used together with the total weight of the batch, including the water, and the specific gravity of the cement, sand and gravel. The following formula was used:

$$\rho = \frac{\left[\frac{W_c}{62.5K_c} + \frac{W_s}{62.5K_s} + \frac{W_g}{62.5K_g}\right]\frac{W_p}{W_b}}{\frac{W_p - W_{pw}}{62.5}}$$

ρ —Density or absolute volume of cement, sand and gravel per unit of concrete volume.
W_c —Weight of cement used in batch.
W_s —Weight of sand used in batch.
W_g —Weight of gravel used in batch.
W_p —Weight of permeability specimen in air.
W_{pw}—Weight of permeability specimen in water.
W_b —Weight of batch including water.
K_c —Specific gravity of cement.
K_s —Specific gravity of sand.
K_g —Specific gravity of gravel.

It will be noted that the first term in the brackets gives the absolute volume of cement in the batch. The absolute volume of cement per cubic foot of concrete was obtained by dividing the absolute volume of cement in the batch by the volume of the batch. This latter value was computed from the weight of the permeability specimen and of the batch and the volume of the permeability specimen.

Absorption—The absorption was calculated for the ½, 6, 24, and 48-hr. intervals using the oven dry weight of the specimen as a basis. The results for the five specimens of any one mix and consistency were averaged and these results are listed in Table 8. In a few cases, when readings were not made exactly on schedule, the results of the individual specimens were plotted and an average curve drawn through these points. The data were then obtained from this graph.

Water-Cement Ratio—The water-cement ratio was computed for the first series and in the four succeeding ones it was kept constant, the amount of mixing water required for the batches being calculated in advance after the moisture content of the aggregate had been determined. A correction was made for the absorption of the aggregate in all of the computations. At the beginning of the second series the total absorption for the aggregate was not known exactly and so the same amount of water was used that was used in the first series. Later, when the water-cement ratios for these batches had been computed, it was found that they were almost exactly the same as those of the first series. The average values are shown in the tables.

RESULTS OF TESTS

Significance of Data from these Permeability Tests—When considering tests of this sort it should be remembered that laboratory tests on the permeability of concrete are qualitative rather than quantitative and that differences between types of apparatus, size and shape of specimens and other differences in the manner of performing the tests make it impossible to compare directly the rate of water flow through concrete of a given composition as determined by different laboratories. Also, it hardly seems possible to reproduce conditions in an actual structure with the small specimens of the laboratory but in a properly conducted laboratory it should be possible to compare the permeability of different concretes under laboratory conditions. It would seem reasonable that of two different concretes the one that showed the greater leakage in the laboratory would also show the greater leakage in an actual structure, but it should not be expected that a concrete which showed water on an exposed face in the laboratory would necessarily do so in an actual structure, or vice versa. In these tests the relative permeabilities of different concretes are compared under laboratory conditions, these conditions having been maintained as nearly constant throughout the test as was possible.

In these tests the flow of water reported represents flow into the specimen and thus includes both the water absorbed by the specimen and that flowing through the specimen. The flow curves plotted from the data cards showed a high initial rate of flow whch gradually decreased as the run continued and the specimen approached the saturation point. The absorption data reported on cylinders from the same concrete showed there was little or no increase in weight after the cylinders had been immersed in water for even 24 hr. so that it is reasonable to suppose that very little of the flow noted for the 40 to 50-hr. period represented water absorbed by the specimen. In Table 10 it can be seen that there is some difference in the flow for the 40 to 50 and 100 to 110-hr. intervals, but since this represents flow under 100 lb. per sq. in. pressure the differences are probably greater than they would be under lower pressure. None of the concrete was wholly impermeable as far as flow into it was concerned, even though the exposed face apparently was perfectly dry. In such cases the

rate of flow for the 40 to 50-hr. period was very low, being less than 0.001 gal. per sq. ft. per hr. in all cases and much less than that in most cases where there was no sign of moisture during the test. Such small amounts of water might readily evaporate on reaching the free surface. As might be expected the flow curves showed that the rate of flow was decreasing slightly even at the end of the 50-hr. period. It has been shown in other tests that the better the curing and the longer the curing continues the less permeable the concrete becomes. The curing conditions during the run were most excellent so that a continuous but very slight decrease in flow might be expected.

Table 8 gives the rate of flow for both the 20 to 50-hr. period and the 40 to 50-hr. period, but only the flow for the latter period will be considered for this report.

For various reasons it was impossible to test all specimens at the same age, but they were removed from the moist room to the dry air of the laboratory at an age of 28 days (a day earlier or later in a few cases as noted in a previous section). These tests and those reported by others indicate but little decrease in permeability after proper curing is discontinued so that the slight average differences in age at the time of testing were disregarded.

It would seem that the method used in these tests of measuring the water flowing into the concrete is superior to those methods which measure the water flowing from the concrete. Concrete of ordinary mixes and properly cured for 28 days is so impermeable that no measurable amount of water escapes from the exposed face, making it necessary to use either much leaner mixes than are ordinarily used in the field or to test the specimens at a very early age. Furthermore there is no way of differentiating between concretes which appear dry on the exposed faces or between concretes permeable enough for the exposed faces to be wet but with not enough flow for it to be measurable. With the method used in these tests any concrete may be tested at any age and the flow of water into the specimen measured.

Relation of Flow to Water-Cement Ratio—Figs. 2 and 3 show flow plotted against water-cement ratio. In Fig. 2, this relation for the 10 most impermeable mixes, is so shown that it is possible to tell at a glance whether the exposed face was dry, somewhat wet or quite wet. In some cases the mix with the lowest water-

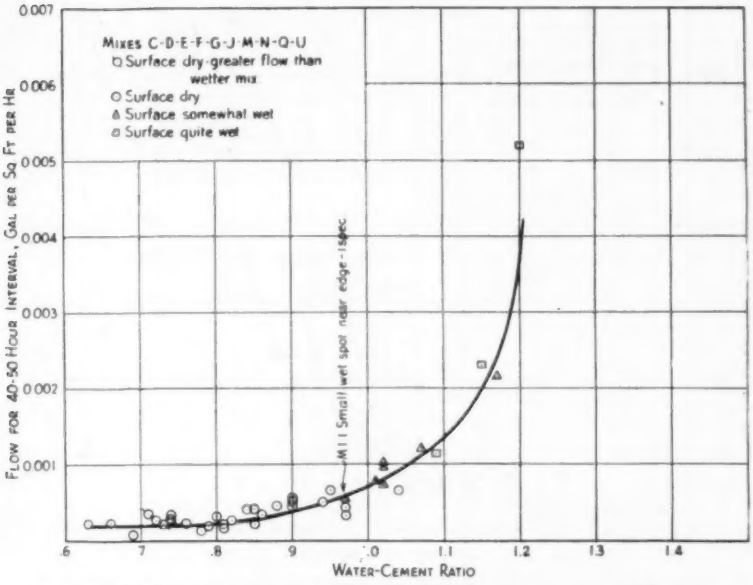

FIG. 2—RELATION OF FLOW TO WATER-CEMENT RATIO FOR MOST IMPERMEABLE MIXES

cement ratio had a greater flow than the same mix with a higher water-cement ratio, although in neither case was there any indication of water on the exposed face of the specimen. Fig. 3, showing the relationship for all mixes, indicates that the correlation between water-cement ratio and flow is only general, and that such other properties as grading of aggregate, richness of mix and consistency affect this relationship to a considerable degree. For instance, of the 10 most impermeable mixes shown in Fig. 2, mixes E, F, G, M and N with 40 per cent Janesville sand and a fineness modulus of 5.5 had about the best grading of aggregate, while mixes C, D, J, Q and U were rich mixes of poorer grading, indicating that with the best grading of aggregate an impermeable concrete can be obtained with a rather lean mix, but with a poorer grading of aggregate a rather rich mix is required.

From a study of Fig. 3 and Table 8 it can be seen that for these tests the exposed face of the specimen was at least somewhat wet whenever the water-cement ratio was over 1.0 (7.5 gal. per sack of cement) with the single exception of mix F-1.2, and that with

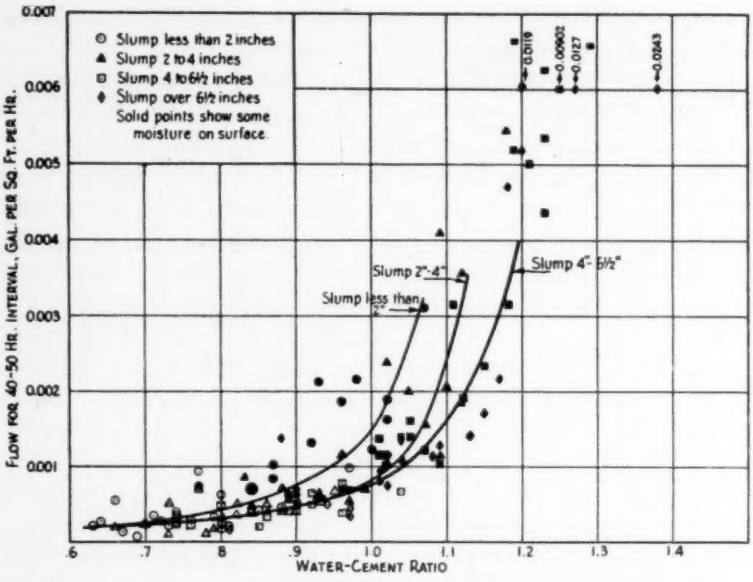

FIG. 3—EFFECT OF WATER-CEMENT RATIO AND SLUMP ON FLOW FOR ALL MIXES

such poorly graded mixes as Y-1.0 and a-1.0 the exposed face was wet although the water-cement ratio was much lower. In Fig. 3 the solid points indicate that the exposed surface was somewhat moist or wet, and their position shows that when the flow was less than 0.0005 gal. per sq. ft. per hr. the exposed face was dry for all mixes, but when the flow was 0.001 gal. per sq. ft. per hr. or more, the exposed face was at least somewhat wet for all mixes.

It might be mentioned at this point that mix R, which was the strongest concrete tested, showed up very badly in all cases where flow was plotted against water-cement ratio, strength or other variables. There was unusual variation between the flow of the different specimens of this mix but not enough to justify discarding any of them from the calculations. It would seem that the mix R (1:4 by volume) should have given at least as good results as mix Q (1:5 by volume) which had the same grading of aggregate. The densities for the two mixes were almost the same.

Relation of Flow to Consistency—This relationship is shown to a certain extent by Fig. 3 but more accurately by Fig. 4. Fig. 3

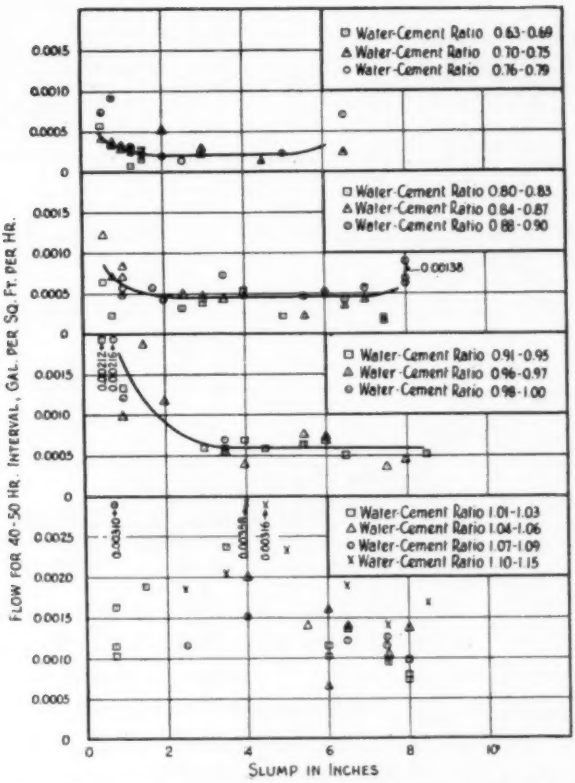
□ Water-Cement Ratio 0.63-0.69
△ Water-Cement Ratio 0.70-0.75
○ Water-Cement Ratio 0.76-0.79
□ Water-Cement Ratio 0.80-0.83
△ Water-Cement Ratio 0.84-0.87
○ Water-Cement Ratio 0.88-0.90
0.00138
□ Water-Cement Ratio 0.91-0.95
△ Water-Cement Ratio 0.96-0.97
○ Water-Cement Ratio 0.98-1.00
□ Water-Cement Ratio 1.01-1.03
△ Water-Cement Ratio 1.04-1.06
○ Water-Cement Ratio 1.07-1.09
x Water-Cement Ratio 1.10-1.15
FLOW FOR 40-50 HR. INTERVAL, GAL. PER SQ. FT. PER HR.
SLUMP IN INCHES

FIG. 4—EFFECT OF CONSISTENCY ON FLOW FOR MIXES OF APPROXIMATELY THE SAME WATER-CEMENT RATIO

indicates that the less permeable mixes are those with low water-cement ratios and that it is possible to have rather impermeable mixes with relatively high slump. The scattering of points made it difficult to draw accurate curves or definite conclusions from Fig. 3. Fig. 4 shows more clearly that the most impermeable mixes are obtained with low water-cement ratios when the slump is at least 2 in., that for higher values of water-cement ratios less impermeable mixes are obtained, and that to obtain the most impermeable mixes for a given water-cement ratio the minimum permissible slump must be increased with increase of water-cement ratio. For very high water-cement ratios the scattering

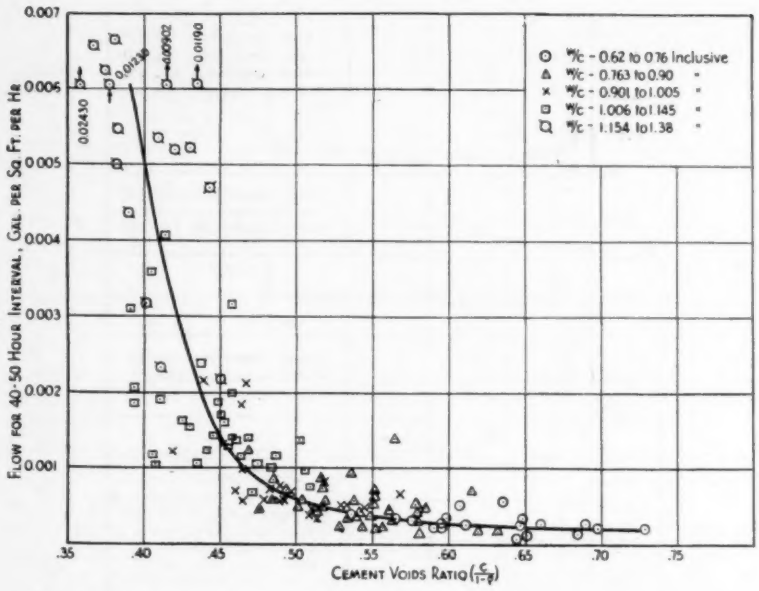

FIG. 5—EFFECT OF CEMENT-VOIDS RATIO AND WATER-CEMENT RATIO ON FLOW FOR ALL MIXES

of points indicates that definite control over the properties of the mix is lost and that, in general, high slumps are required for the most impermeable concrete. It should be remembered that all mixes used in these tests had sufficient water to make them plastic and workable and that those mixes with a slump of less than 2 in. obeyed the water-cement-strength law even though the flow of water through them was, in most cases, greater than mixes of slightly higher slump. In 15 cases the 1.1 mix showed a lesser flow than the 1.0 mix and in 9 of these mixes the average slump for the 1.1 mix was from 2 to 3 in. In 19 cases the 1.1 mix showed a greater flow than the 1.0 mix and in 12 of these the average slump was over 3 in. The water-cement ratio of the 1.1 mix was 10 per cent greater than that of the 1.0 mix, while the flow of water was less for the 1.1 mix in the majority of cases where the slump of the 1.1 mix was from 2 to 3 in. This confirms what has been found in other permeability tests; that a wetter mix is required for minimum flow than is required for maximum strength.

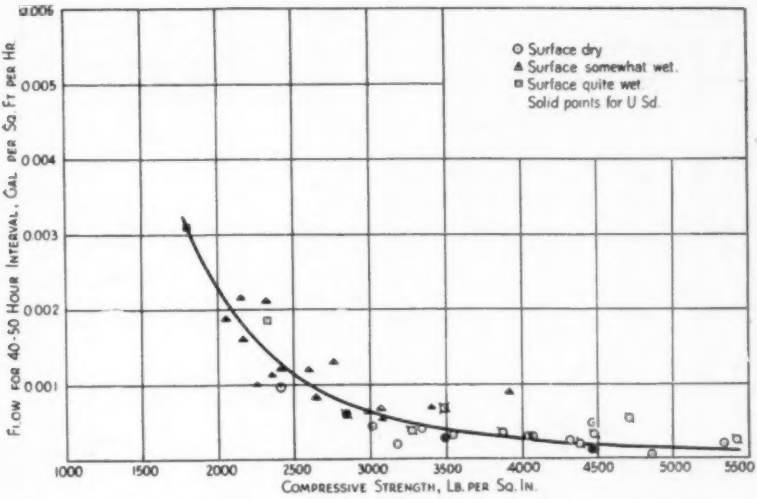

FIG. 6—RELATION OF COMPRESSIVE STRENGTH TO FLOW FOR MIXES WITH SLUMP LESS THAN 2 INCHES

Relation of Flow to Cement-Voids Ratio—Fig. 5 shows flow plotted against cement-voids ratio for all mixes, and with varying ranges of water-cement ratio. From this figure it would seem that there is a slightly more definite relationship between flow and cement-voids ratio than between flow and water-cement ratio. It is reasonable that this should be the case, for the grading of aggregate and consistency, which are important in influencing the flow affect the value of the cement-voids ratio but not the water-cement ratio. The slump, however, had some effect on the relation of flow to cement-voids ratio, for when the data were separated into four slump ranges and plotted, the curve for the 2 to 4 in. slump was farthest to the left.

Relation of Flow to Compressive Strength—Figs. 6 and 7 show flow plotted against compressive strength for two ranges in slump; the former figure for mixes with slump less than 2 in. and the latter for mixes with slump over 6½ in. Space does not permit publication of the curves for mixes with slumps from 2 to 4 in. and from 4 to 6½ in. These two curves lie within those shown in Figs. 6 and 7, with a shift to the left as the slump increases. There is apparently a somewhat closer relationship

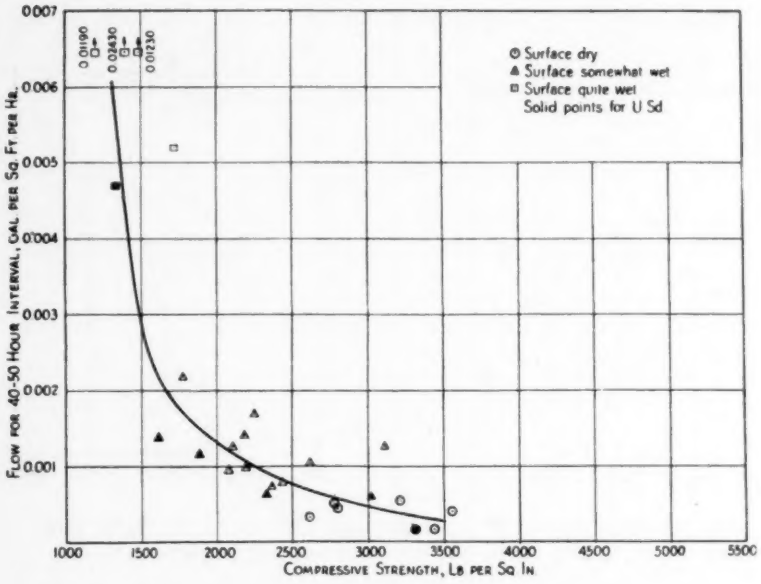

FIG. 7—RELATION OF COMPRESSIVE STRENGTH TO FLOW FOR MIXES WITH SLUMP OVER 6½ INCHES

between flow and strength than between flow and water-cement ratio. In these tests only one mix having a strength of over 3500 lb. per sq. in. showed any moisture on the exposed face, while all mixes with a strength of less than 2250 lb. per sq. in. showed some moisture on the exposed surface.

Relation of Flow to Proportion of Cement—Fig. 8 shows the cement-dry aggregate ratio (by weight) plotted against flow for mixes with a 2 to 4-in. slump. Average curves for mixes with other ranges of slump lie to the right of the one shown in the figure. They indicate that, in general, rich mixes are most impermeable.

Relation of Flow to Grading Aggregate—Fig. 9 shows flow plotted against fineness modulus for various proportions of cement and for two ranges of slump. The 1-4 and 1-5 mixes by volume agree with what has been shown already; i. e., that the more impermeable mixes are those with slumps greater than that required for normal consistency. The 1-6 mixes, however, show a marked

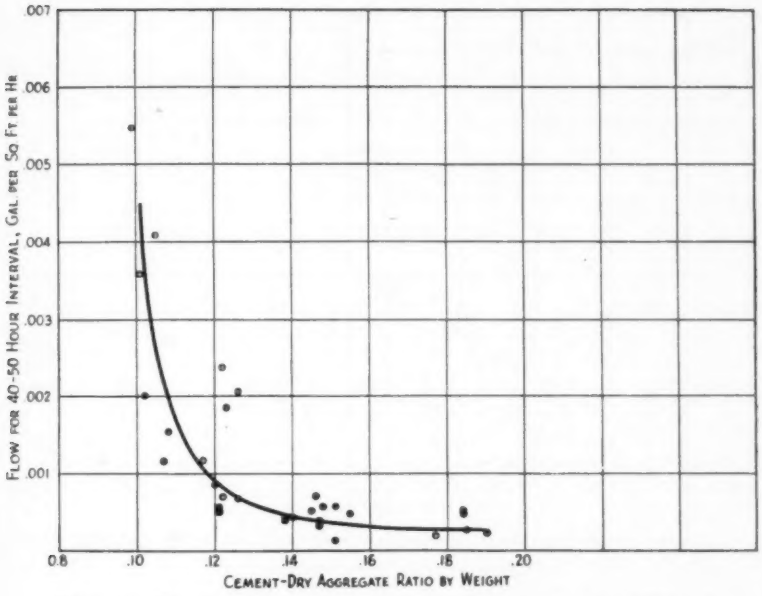

FIG. 8—RELATION OF CEMENT-DRY AGGREGATE RATIO TO FLOW FOR MIXES WITH 2 TO 4-INCH SLUMP

difference. In plotting this graph it was very difficult to obtain good curves unless the slump was restricted to narrow limits, and naturally only a few mixes could be used. This curve is not entirely irreconcilable with what is shown in Fig. 4, for it represents lean mixes of poor or fair grading, and it might be expected that for these the most impermeable concrete is that with only enough water to make it plastic. Fig. 9 indicates that as mixes become leaner, the fineness modulus must increase if minimum flow is desired. Roughly this variation is from a fineness modulus of 5.2 for a 1-4 mix to 5.8 for a 1-6 mix by volume.

The previous paragraphs indicate that a well graded aggregate is even more important from the standpoint of water tightness than it is from the standpoint of strength. A study of the grading of aggregate for the 10 most impermeable mixes shown in Fig. 2 indicate that when large sizes of coarse aggregate predominate, as for mixes C, D, E, F, G, J, M and N, rich mixes like 1-4 or 1-5 should be used when the mixes are slightly over or under sanded

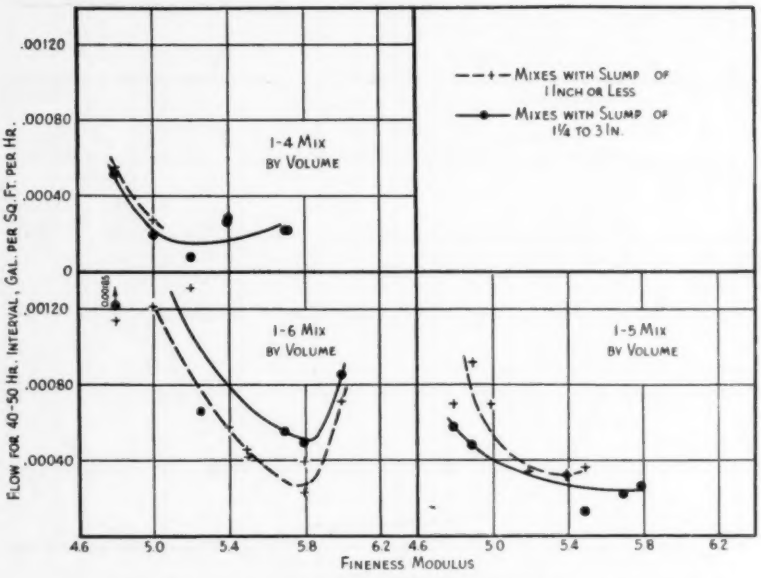

FIG. 9—RELATION OF FINENESS MODULUS TO FLOW FOR MIXES WITH SLUMP LESS THAN 3 INCHES

(50 or 35 per cent sand), but where the proportion of sand is 40 per cent by weight of the mixed aggregate the leaner mixes like 1-5 or 1-6 may be used. When the smaller sizes of coarse aggregate predominate, as in mixes Q and U, a 1-5 mix can be used with 35 per cent sand but this mix must be made richer when a greater proportion of sand is used.

Relation of Compressive Strength to Absorption—Fig. 10 shows this relationship for Janesville sand mixes. The one for University sand was similar but is not shown. In general the higher values of fineness modulus showed least absorption, but there was little difference for the best concretes.

Relation of Water-Cement Ratio to Absorption—Fig. 11 shows this relationship for mixes with a 1½ to 3-in. slump. In plotting this graph, as in some previous cases, it was necessary to restrict the consistency to narrow limits in order to obtain a satisfactory curve. As might be expected the absorption increases with an increase in water-cement ratio.

Relation of Flow to Absorption—Graphs showing this relation-

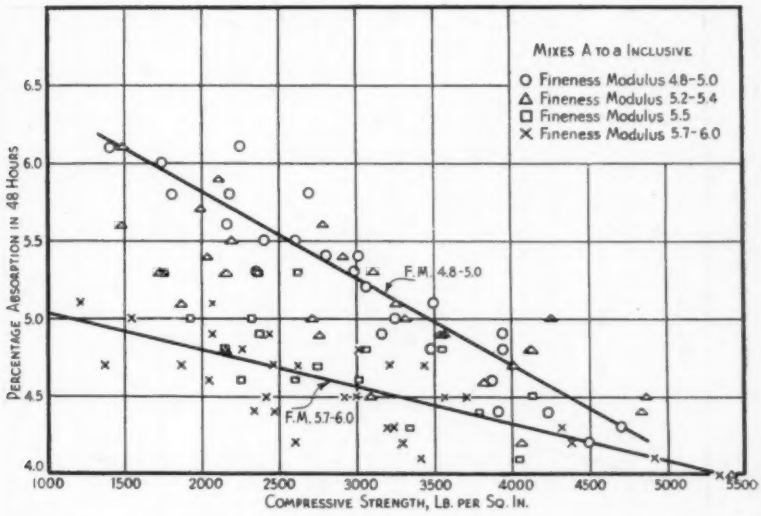

FIG. 10—RELATION OF COMPRESSIVE STRENGTH TO ABSORPTION FOR JANESVILLE SAND MIXES

ship were plotted but the individual points were spread too much to draw curves through them. Those mixes with the least flow had least absorption. This agrees with Fig. 12 which shows that mixes with greater density had least absorption.

Relation of Strength to Water-Cement Ratio—Fig. 13 shows the familiar relationship of strength to water-cement ratio. It is to be noted that the University sand mixes have less strength for given values of water-cement ratio than the Janesville sand mixes. The University sand was very fine and poorly graded, hence mixes containing it had lower strength than similar mixes of Janesville sand.

High Pressure Test Results—Some six months after the testing had been finished at the 40 lb. per sq. in. pressure 19 mixes were selected as representative ones and tested for 110 hr. at 100 lb. per sq. in. pressure. The results of these tests are shown in Table 10 and Fig. 14. The age of the specimens when first tested at the lower pressure averaged about 40 days and that of seven of these when retested about 150 days. The age when tested at the higher pressure averaged about 14 months. Fig. 14 shows, how-

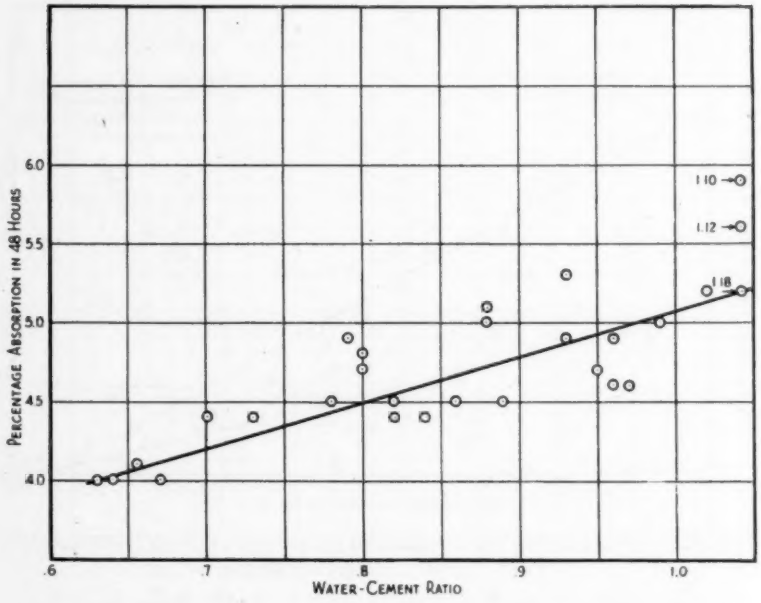

FIG. 11—RELATION OF WATER-CEMENT RATIO TO ABSORPTION FOR MIXES WITH 1½ TO 3-INCH SLUMP

ever, that the flow at the lower pressure of the 40 to 50-hr. interval is about 60 per cent of that for the higher pressure. Had this second series of tests been made at the lower pressure the two curves in the left half of the figure would more nearly coincide. It is evident, therefore, that an increase in age after 40 days has only slight effect on the watertightness. The right hand half of the figure shows the results at the higher pressure for the 100 to 110-hr. interval. It is interesting to note that this curve and the one for the low pressure in the other half of the figure are coincident up to a water-cement ratio of 0.90, and that after a water-cement ratio of 1.00 the curve for the higher pressure increases more sharply. One of the 19 mixes (X-1.35) that had shown moisture on the exposed surface in the original tests appeared dry at the higher pressure, while four of the mixes (F-1.1, G-1.1, U-1.2 and X-1.0) which had previously appeared dry now showed some moisture on the surface.

Long-Time Test Results—Fig. 15 shows flow plotted against

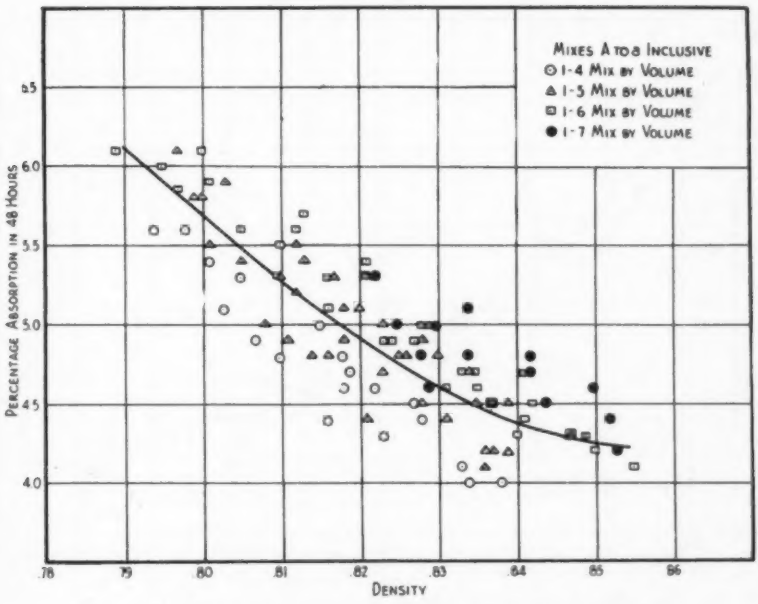

FIG. 12—RELATION OF DENSITY TO ABSORPTION FOR JANESVILLE SAND MIXES

time for several mixes. These tests were made in three installments; the first for 500 hr., the second for 1000 additional hours and the third for 3000 more hours. The dotted portions of the curves indicate these breaks in the testing. About five months elapsed between the first two runs but the specimens were not removed from the apparatus during this interval. The water remained in the casting; the air pressure was turned off. At the end of a total of 1500 testing hours various indigo dyes were added to the water in the hope of having the coloring show on the exposed surface but none was noticeable after 3000 hr., although the slopes of the curves remained constant. It may be possible that the voids in the concrete act similarly to those in charcoal and that the dyes were absorbed as are poisonous gases by the charcoal. Unfortunately the glass water tube on the casting holding the specimen 5-L1.0 was broken at the start of the run. Mix 4-X1.35 was not tested in the original 500-hr. run.

This long time testing was carried on to determine whether or not the flow of water into the specimen would continue only until

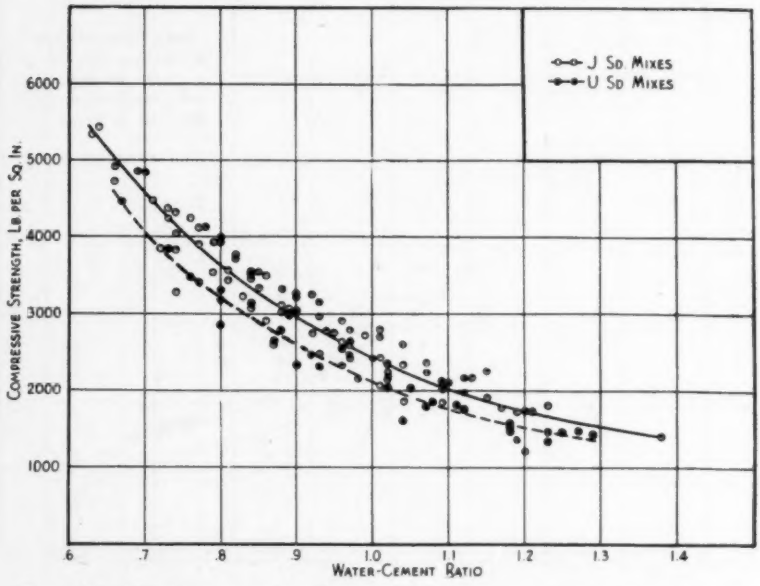

FIG. 13—RELATION OF WATER-CEMENT RATIO TO COMPRESSIVE STRENGTH FOR ALL MIXES

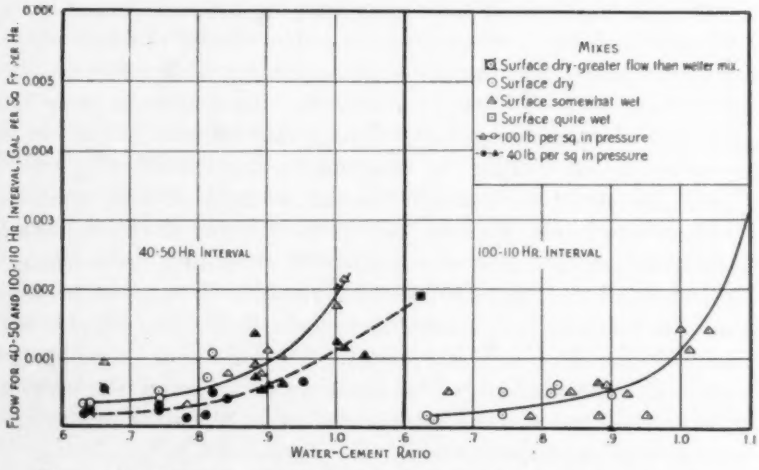

FIG. 14—EFFECT OF VARYING PRESSURE AND TIME ON THE WATER-CEMENT RATIO—FLOW RELATIONSHIP

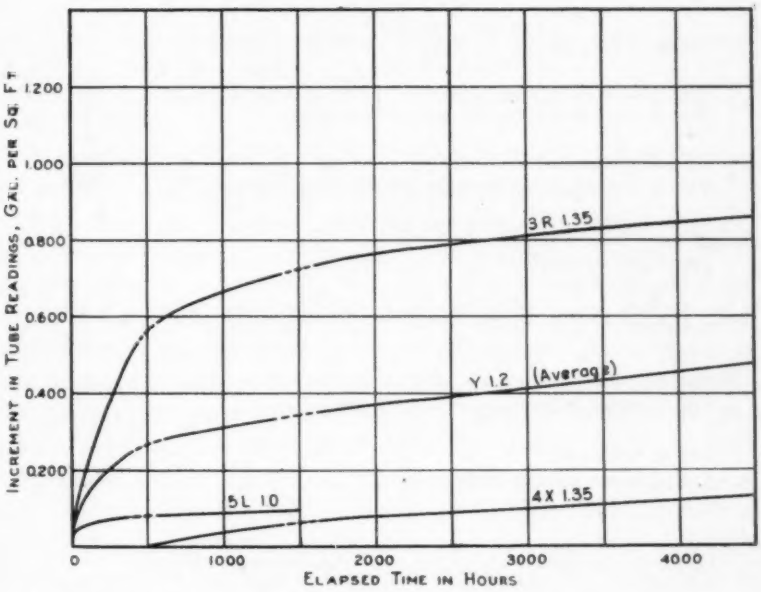

FIG. 15—TIME-FLOW CURVE FOR VARIOUS MIXES UNDER 100 LB. PER SQ. IN. PRESSURE

the voids had been completely filled, and whether the voids would become clogged by sediment or bacterial action in the water. It is evident from the figure that some clogging of the voids did take place but that it was not enough to prevent flow through the specimen at 100 lb. per sq. in. pressure.

The following calculations show the amount of water that must have passed through the specimen during the test run. Tests reported by F. R. McMillan in "Basic Principles of Concrete Making" (p. 9-11) indicated that approximately 0.20 of the volume of cement was combined water and this figure was used in the following calculations.

Mix 3-R-1.35

Permeability Specimen		Materials in Mix	
Weight	36.65 lb.	Cement	19.5 lb.
Volume	0.243 cu. ft.	Cement and Agg.	125.5 lb.
Density	0.805	Water used	12.64 lb.
		Absorption	1.35 lb.
			0.188 cu. ft.

$a + b + c = (0.805 \times 0.243) =$

Vol. water combined $\frac{36.65}{138.1} \times \frac{19.5}{94} \times 0.20 = 0.011$

Vol. water voids $\frac{36.65}{138.1} \times \frac{11.3}{62.5} - 0.011 = 0.037$

Abs. vol. cement, agg., combined water and water voids	0.236 cu. ft.
Vol. of water entering specimen (0.431 gal.)	0.0575
	0.2935
Vol. of specimen	0.243
Vol. of water passing through specimen in 4500 hours	0.0505 cu. ft.

Mix Y 1.2

Permeability Specimen		Materials in Mix	
Weight	36.05 lb.	Cement	19.5 lb.
Volume	0.236 cu. ft.	Cement and Agg.	126.5 lb.
Density	0.801	Water used	12.57 lb.
		Absorption	.89 lb.

Abs. vol. cement agg., combined water and water voids	0.239 cu. ft.
Vol. of water entering specimen (0.236 gal.)	0.0315
	0.2705
Vol. of specimen	0.236
Vol. of water passing through specimen in 4500 hrs.	0.0345 cu. ft.

Mix 5 L 1.0

Permeability Specimen		Materials in Mix	
Weight	38.10 lb.	Cement	15.7 lb.
Volume	0.247 cu. ft.	Cement and Agg.	124.5 lb.
Density	0.847	Water used	8.76 lb.
		Absorption	.89 lb.

Abs. vol. of cement, agg., combined water and water voids	0.244 cu. ft.
Vol. of water entering specimen	0.0066
	0.2506
Vol. of Specimen	0.247
Vol. of water passing through specimen in 1500 hrs.	0.0036 cu. ft.

Undoubtedly some water was lost in the drying of the specimens before they were tested in the later runs. During this interval they were stacked either out of doors or in the dry air of the laboratory with their cylindrical sides still covered with asphalt. It is probable that they lost about 1 per cent of moisture by weight. Tests on absorption indicate, however, that concrete will absorb approximately 1½ per cent by weight when immersed in water for a half hour (see Table 8). Since at least a half hour elapsed after the permeability tubes had been filled with water and the pressure turned on and before the readings were taken, the evaporation was counterbalanced by the absorption (under pressure) and no account of it was taken in the preceding calculations. These computations together with the constant slope of the curves of Fig. 15 indicate that water will flow through even

good concrete (5 L-1.0 mix) although the flow may be slow enough so that the surface appears dry.

SUMMARY

The results of these tests, have been analyzed in the previous section and may be summarized as follows:

1. It might be expected that the permeability would increase as the water-cement ratio increased and these tests indicate that there is such a relationship. However, this relationship is influenced considerably by the consistency and, especially with the leaner mixes, by the grading of the aggregate. More water is required for minimum permeability than for maximum strength, the permeability increasing when the water is reduced below the amount required for a slump of about 2 to 3 in.

2. Permeability decreases as strength increases and these tests indicate that this relationship may be somewhat closer than that between the water-cement ratio and permeability, although there is no apparent reason why this should be so if the relationship between water-cement ratio and strength is as fundamental as it is generally believed to be.

3. Permeability decreases as the cement-voids ratio increases and this relationship also seems to be more definite than that bebetween the water-cement ratio and permeability, apparently because of the effect that the grading of the aggregate and the consistency have on the cement-voids ratio.

4. These tests indicate that there is no relationship between permeability and absorption, except the very general one that a good concrete might be expected to be lower both in permeability and absorption than a poor concrete.

5. These tests indicate that for the comparatively small specimens used there is little change in permeability after the concrete is removed from the moist room into a dry atmosphere, and that even considerable differences in age at time of testing are immaterial, if the age at which the specimens are removed from the moist room is kept constant. In the average structure the concrete as a whole would not dry out so rapidly and the concrete might be expected to decrease in permeability for a considerable time. It may well be, however, that the concrete near the surface may be affected in the same way as the laboratory specimens, and

this would be of considerable importance if such a surface was exposed to the weather and to repeated freezings and thawings.

6. Tests at higher pressure indicate that more water will flow through the specimen, but the increased flow is not directly proportional to the added pressure. Long time tests under high pressure show that clogging of the void spaces is not enough to prevent flow through concrete although the flow may be slow enough so that the surface appears dry.

TABLE 1—CHEMICAL ANALYSIS OF CEMENT—MANUFACTURERS' TESTS

Kind of Cement	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	MnO	Loss on Ignition	Total
Atlas	21.72	2.48	5.68	62.98	3.17	1.89	....	0.99	98.91
Lehigh	21.82	2.45	5.87	62.76	2.69	1.73	....	....	97.32
Universal	22.00	2.05	5.59	64.50	1.96	1.62	0.82	1.53	100.04

TABLE 2—PHYSICAL TESTS OF CEMENT

Property	Mftrs. Reports			University of Wis. Tests			
	Atlas	Lehigh	Univ.	Atlas	Lehigh	Univ.	Mixture
Normal Consistency	22.0	22.0	....	23.0	23.0	23.0	23.0
Initial Set*	2:35	4:15	3:05	3:05	4:10	4:00	....
Final Set*	5:15	6:50	....	7:45	7:35	8:35	....
Soundness	OK	OK	OK	OK	OK	OK	OK
Fineness	92.8	82.5	84.2	93.0	82.7	85.9	87.7
Tensile Strength 1-3 Std. Mortar Briquets							
1 day		95					
3 day		192		287	236†	239	305†
7 day	355	283	290	394	315	325	323
28 day		383	385	493	416	428	456
60 day				479	420	471	480
180 day				449	387	470	448
360 day				433	320	302	372
Specific Gravity							3.13
Compressive Strength 1-3 Std. Mortar 2 in. x 4 in. Cylinders							
7 day	3408						
14 day							3090
30 day							3228
62 day							3960
180 day							4114
360 day							4350
Tensile Strength Neat Cement Briquets							
1 day				453	297	285	468
7 day				786	767	736	700
28 day							776
60 day							701
360 day							601

*Gillmore Needle.
†4-day strength.

TABLE 3—PHYSICAL PROPERTIES OF SANDS

Kind	Fineness Modulus	Wt. per Cu. Ft.	Per Cent Voids	Absorption by Wt. of Sand Per Cent	Sp. Gr.
Janesville Sand	2.73	115	32.7	0.78	2.70
University Sand	1.53	108	34.0	0.40	2.64

TABLE 4—SIEVE ANALYSIS OF SANDS

Kind	Per Cent Coarser by Weight Number of Sieve					
	4	8	14	28	48	100
Janesville Sand	1.5	14.6	32.5	47.6	80.0	97.0
University Sand	0	0	2.0	8.0	32.0	91.0

TABLE 5—PHYSICAL PROPERTIES AND GRADING OF COARSE AGGREGATES

Gravel for Mixes	Parts by Weight—Size				Physical Properties			
	¼–⅜	⅜–¾	¾–1½	1½–2	F. M.	Absorption by Wt. of Gravel Per Cent	Sp. Gr.	Sp. Wt. lb. per cu. ft.
A to J, b to k	1	2	2.5	–	7.3	1.59	2.68	107.7
K to N	1	2	4	–	7.4	1.55	2.68	106.5
O to X	2	2	1	–	6.8	1.71	2.67	108.6
Y	1	2	–	–	6.7	1.75	2.67	105
Z to n	1	2	2	2	7.7	1.55	2.68	110

TABLE 6—GRADING OF MIXES

Mix	Mix by Volume		Per Cent Fine Agg. by Wt.	Per Cent Coarse Agg. by Wt.	Mix by Wt.	Wt. per Cu. Ft. lb.	F. M.
A	1:7	1:2.65:5.26	35	65	1:3.24:6.01	125	5.7
B	1:6	1:2.27:4.52			1:2.78:5.18		
C	1:5	1:1.89:3.76			1:2.32:4.31		
D	1:4	1:1.51:3.00			1:1.85:3.44		
E	1:7.09	1:3.13:4.86	40.7	59.3	1:3.84:5.55	125	5.5
F	1:6	1:2.60:4.16	40	60	1:3.18:4.77		
G	1:5	1:2.16:3.47			1:2.65:3.98		
H	1:5.62	1:3.25:3.52	50	50	1:3.99:3.99	133	5.0
I	1:4.69	1:2.71:2.93			1:3.32:3.32		
J	1:4	1:2.31:2.50			1:2.84:2.84		
K	1:6	1:2.37:4.76	35	65	1:2.90:5.38	130	5.8
L	1:5	1:1.98:3.97			1:2.42:4.50		
M	1:6	1:2.71:4.40	40	60	1:1.31:4.97	130	5.5
N	1:5	1:2.26:3.66			1:2.76:4.15		
O	1:7	1:2.73:5.37	35	65	1:3.34:6.20	128	5.4
P	1:6	1:2.34:4.60			1:2.88:5.35		
Q	1:5	1:1.95:3.83			1:2.39:4.43		
R	1:4	1:1.56:3.06			1:1.91:3.53		
S	1:6	1:2.69:4.28	40	60	1:3.29:4.94	129	5.2
T	1:5	1:2.24:3.57			1:2.74:4.12		
U	1:4	1:1.79:2.86			1:2.19:3.32		
V	1:6	1:3.33:3.52	50	50	1:4.08:4.08	128	4.8
W	1:5	1:2.77:2.94			1:3.39:3.39		
X	1:4	1:2.22:2.35			1:2.72:2.72		
Y	1:5	1:2.39:3.20	45	55	1:2.92:3.56	122	4.9
Z	1:7	1:2.80:5.44	35	65	1:3.44:6.40	132	6.0
a	1:6	1:2.40:4.66			1:2.93:5.46		
b	1:7	1:2.60:6.08	30	70	1:2.98:6.98	134	5.6
d	1:6	1:2.23:5.22			1:2.56:6.00		
e	1:5	1:1.86:4.35			1:2.14:5.01		
f	1:4	1:1.49:3.48			1:1.71:4.00		
g	1:7	1:3.08:5.73	35	65	1:3.52:6.55	136	5.3
h	1:6	1:2.65:4.92			1:3.01:5.58		
k	1:5	1:2.21:4.10			1:2.53:4.69		

TABLE 7—RESULTS OF COMPRESSION TESTS

Mark	Mix by Volume	Percentage of Sand	Water-Cement Ratio	Slump in in.	Flow Factor	Compressive Strength in lb. per sq. in.		Percentage Loss in Strength for Absorption Specimen	Age in Days of Absorption Specimen when Broken
						Normal at 28 Days	For Absorption Specimen		
A1.0	1:7	35	0.97	1	145	2410	2230	7.4	69
A1.1			1.07	4	170	2260	1730	23.4	69
A1.2			1.18	6½	200	1530	1410	7.8	62
B1.0	1:6	35	0.89	1¾	155	2990	2820	5.6	62
B1.1			0.96	5½	175	2620	2300	12.2	61
B1.2			1.05	6	195	2060	1810	12.2	61
B1.35			1.20	7½	225	1210	1070	11.5	64
C1.0	1:5	35	0.73	1¼	130	4380	4000	8.6	59
C1.1			0.81	5	185	3560	2940	17.4	60
C1.2			0.90	7	200	3210	2670	16.8	60
C1.35			1.01	8	230	2430	2000	17.7	59
D1.0	1:4	35	0.63	1½	125	5330	4980	6.5	59
D1.1			0.66	3	145	4920	4510	8.3	59
D1.2			0.74	6½	190	3830	3570	6.7	60
D1.35			0.81	7½	230	3430	3070	10.4	59
E1.0	1:7.1	40.7	1.02	¾	130	2250	2110	6.2	59
E1.1			1.09	2½	160	2140	1950	8.8	59
E1.2			1.15	5	180	1920	1630	15.1	57
F1.0	1:6	40	0.85	1	130	3340	3010	9.8	56
F1.1			0.95	4	170	2750	2450	10.8	56
F1.2			1.04	6	200	2320	2050	11.7	55
F1.35			1.17	7	230	1770	1390	21.5	55
G1.0	1:5	40	0.71	¾	115	4480	3690	19.8	53
G1.1			0.78	2½	145	4130	3450	16.6	53
G1.2			0.85	5½	185	3550	3000	15.4	56
G1.35			0.97	7½	225	2620	2150	17.8	55
H1.0	1:5.6	50	1.00	1	130	2410	2070	14.1	54
H1.1			1.10	3½	165	2100	1710	18.6	54
H1.2			1.21	6½	205	1740	1410	19.0	53
I1.0	1:4.7	50	0.84	1	125	3070	2610	15.0	53
I1.1			0.93	3½	165	2980	2520	15.4	53
I1.2			1.01	6½	225	2700	2130	21.1	53
I1.35			1.15	8½	245	2250	1800	20.0	53
J1.0	1:4	50	0.72	1	120	3870	3770	2.6	70
J1.1			0.79	2	145	3940	3590	8.8	74
J1.2			0.86	6½	195	3500	3210	8.2	74
J1.35			0.97	8	235	2790	2600	6.8	74
K1.0	1:6	35	0.74	½	120	3280	3170	3.3	59
K1.08			0.80	¾	130	3180	2840	10.7	61
K1.16			0.86	2½	155	2910	2540	12.7	60
K1.3			0.97	6	185	2460	2030	17.4	61
L1.0	1:5	35	0.74	1¼	130	4320	3740	13.3	55
L1.1			0.82	4	170	3710	3080	16.9	55
L1.2			0.89	6½	205	3010	2480	17.6	55
L1.35			1.01	7½	235	2070	1740	15.9	55
M1.0	1:6	40	0.88	1	120	3010	2740	8.9	54
M1.1			0.97	3½	155	2600	2510	3.4	56
M1.2			1.07	6½	210	2370	1960	17.3	56
M1.35			1.20	7	230	1730	1360	21.3	55

TABLE 7—RESULTS OF COMPRESSION TESTS—CONTINUED

Mark	Mix by Volume	Percentage of Sand	Water-Cement Ratio	Slump in in.	Flow Factor	Compressive Strength in lb. per sq. in.		Percentage Loss in Strength for Absorption Specimen	Age in Days of Absorption Specimen when Broken
						Normal at 28 Days	For Absorption Specimen		
N1.0	1:5	40	0.74	¾	120	4040	3670	9.2	58
N1.1			0.82	3	145	3780	3290	12.9	58
N1.2			0.90	6	195	3060	2790	8.8	73
N1.35			1.02	8	235	2360	2120	10.1	73
O1.0	1:7	35	0.98	¾	135	2150	1940	9.7	63
O1.1			1.09	2½	165	1870	1610	13.8	63
O1.2			1.19	5	185	1730	1370	20.8	63
P1.0	1:6	35	0.89	1	130	3080	2730	11.3	64
P1.1			0.99	3½	165	2710	2250	17.0	54
P1.2			1.09	6	195	2030	1740	14.2	54
P1.35			1.23	6½	215	1480	1230	16.9	54
Q1.0	1:5	35	0.74	1	125	4060	3780	6.7	54
Q1.1			0.80	2½	145	4000	3320	17.0	54
Q1.2			0.90	5½	190	3260	2760	15.3	54
Q1.35			1.02	8	225	2190	1800	17.8	54
R1.0	1:4	35	0.64	1½	125	5420	4940	8.7	52
R1.1			0.70	3	160	4830	4290	11.1	52
R1.2			0.77	6½	200	4120	3740	9.2	52
R1.35			0.88	8	240	3110	2580	17.0	52
S1.0	1:6	40	0.92	1	140	2760	2330	15.6	52
S1.1			1.02	3½	170	2160	1830	15.3	52
S1.2			1.12	6½	205	1990	1610	19.1	50
S1.35			1.27	8	240	1490	1190	20.1	50
T1.0	1:5	40	0.79	¾	130	3540	3070	13.2	52
T1.1			0.88	3½	165	3310	2980	9.9	58
T1.2			0.96	6	205	2920	2400	17.8	58
T1.35			1.09	7½	240	2110	1850	12.2	58
U1.0	1:4	40	0.69	1¼	135	4860	4420	9.0	58
U1.1			0.76	5	185	4250	3670	13.7	57
U1.2			0.84	7	215	3550	3290	7.3	57
U1.35			0.94	8½	245	2780	2460	11.5	57
V1.0	1:6	50	1.02	¾	130	2360	1960	17.0	59
V1.1			1.12	2½	160	2170	1840	15.2	53
V1.2			1.23	6½	200	1810	1500	17.1	53
V1.35			1.38	7½	240	1410	1230	12.7	53
W1.0	1:5	50	0.84	¾	125	3480	3050	12.3	53
W1.1			0.93	3	160	3160	2870	9.2	53
W1.2			1.01	6	210	2800	2400	14.3	57
W1.35			1.13	7½	240	2180	1850	15.2	57
X1.0	1:4	50	0.66	½	120	4710	4480	4.7	57
X1.1			0.73	2	140	4230	4100	3.0	56
X1.2			0.80	4	180	3940	3540	10.1	56
X1.35			0.90	8	225	3020	2890	4.3	57
Y1.0	1:5	45	0.77	¾	125	3910	3660	6.3	57
Y1.1			0.84	3	135	3490	3030	13.2	57
Y1.2			0.92	5½	205	3250	2850	12.3	56
Y1.35			1.04	7½	235	2610	2050	21.4	56

TABLE 7—RESULTS OF COMPRESSION TESTS—CONTINUED

Mark	Mix by Volume	Percentage of Sand	Water-Cement Ratio	Slump in in.	Flow Factor	Compressive Strength in lb. per sq. in.		Percentage Loss in Strength for Absorption Specimen	Age in Days of Absorption Specimen when Broken
						Normal at 28 Days	For Absorption Specimen		
Z1.0	1:7	35	0.87	½	120	2600	2230	14.3	58
Z1.1			0.96	1½	135	2330	2080	10.7	55
Z1.2			1.05	4	165	2040	1710	16.2	55
Z1.35			1.19	6	190	1370	1250	8.7	55
a1.0	1:6	35	0.77	½	120	3410	3240	5.2	55
a1.1			0.83	2	130	3230	2890	10.5	61
a1.2			0.93	4½	180	2470	2170	12.2	62
a1.35			1.04	6½	205	1870	1520	18.7	62
b1.0	1:7	30	1.02	¾	120	2160	1950	9.7	53
b1.1			1.12	4	160	1760	1470	16.4	53
b1.2			1.23	6	185	1330	1230	7.5	53
d1.0	1:6	30	0.87	1	120	2640	2320	12.1	52
d1.1			0.96	2	145	2560	2180	14.8	52
d1.2			1.05	5½	185	2070	1600	22.7	52
d1.35			1.18	7½	210	1480	1190	19.6	52
e1.0	1:5	30	0.76	1¼	120	3490	3130	10.2	52
e1.1			0.84	3½	155	3130	2690	14.1	50
e1.2			0.92	6½	205	2480	2040	17.7	50
e1.35			1.04	8	240	1610	1430	11.2	50
f1.0	1:4	30	0.67	1½	130	4470	4060	9.2	50
f1.1			0.73	4½	160	3850	3540	8.0	50
f1.2			0.80	7½	200	3310	2790	15.7	50
f1.35			0.90	8	245	2330	2060	11.6	49
g1.0	1:7	35	1.07	¾	120	1800	1550	13.8	49
g1.1			1.18	2½	140	1590	1370	13.8	55
g1.2			1.29	4½	175	1420	1250	11.9	55
h1.0	1:6	35	0.93	½	120	2320	2120	8.6	55
h1.1			1.02	1½	130	2050	1870	8.8	58
h1.2			1.11	4½	170	1820	1580	13.2	58
h1.35			1.25	6½	225	1470	1210	17.7	58
k1.0	1:5	35	0.80	½	120	2850	2560	10.1	59
k1.1			0.88	2	135	2790	2570	7.8	59
k1.2			0.96	4	165	2570	2220	13.6	58
k1.35			1.08	7½	225	1880	1610	14.3	58

TABLE 8—RESULTS OF FLOW AND ABSORPTION TESTS

Mark	Mix by Volume	Water-cement Ratio	Flow Tests						Percentage of Absorption after				
			Flow in gal. per sq. ft. per hr.		Max. Plus Variation from Aver. 40-50 hr. Flow, per cent	No. of Specimens Tested	Average Age in Days at First Testing	Age in Days at Re-testing	½ hr.	6 hr.	24 hr.	48 hr.	
			20-50 hr. Interval	40-50 hr. Interval									
A1.0	1:7	0.97	0.00119	0.00098	135	5	34	90–100	1.5	3.7	4.5	4.5	⊙
A1.1		1.07	.00179	.00154	95	5	34	100–108	1.7	3.9	4.7	4.8	△
A1.2		1.18	.00354	.00316	46	4	33	108	1.7	4.2	5.0	5.0	□
B1.0	1:6	0.89	0.00070	0.00056	150	5	43	90	1.4	3.4	4.4	4.5	△
B1.1		0.96	.00087	.00078	54	5	42	100	1.5	3.6	4.6	4.7	⊙
B1.2		1.05	.00173	.00160	150	4	30	91	1.6	4.1	4.9	4.9	□
B1.35		1.20	.....	.01190	51	3	38	244	1.8	4.4	5.1	5.1	□
C1.0	1:5	0.73	0.00031	0.00022	82	4	35	450	1.3	3.0	4.0	4.2	⊙
C1.1		0.81	.00030	.00021	55	4	37	—	1.4	3.4	4.5	4.5	⊙
C1.2		0.90	.00063	.00056	79	4	48	—	1.4	3.7	4.6	4.7	⊙
C1.35		1.01	.00092	.00080	88	3	36	—	1.6	4.0	4.9	4.9	△
D1.0	1:4	0.63	0.00022	0.00022	67	5	38	90	1.2	2.8	3.8	4.0	⊙
D1.1		0.66	.00027	.00022	164	5	35	85	1.3	3.0	4.0	4.1	⊙
D1.2		0.74	.00029	.00025	77	5	35	—	1.6	3.6	4.6	4.6	⊙
D1.35		0.81	.00023	.00019	28	5	35	90	1.5	3.6	4.6	4.7	⊙
E1.0	1:7.1	1.02	0.00123	0.00102	18	4	43	—	1.4	3.6	4.5	4.6	△
E1.1		1.09	.00152	.00116	81	4	42	—	1.6	3.8	4.8	4.8	□
E1.2		1.15	.00280	.00232	77	4	34	90	1.6	4.1	5.0	5.0	□
F1.0	1:6	0.85	0.00049	0.00042	105	5	41	—	1.3	3.3	4.2	4.3	⊙
F1.1		0.95	.00083	.00068	32	5	41	103	1.4	3.7	4.7	4.7	⊙
F1.2		1.04	.00086	.00068	47	5	44	93	1.6	4.0	4.9	5.0	⊙
F1.35		1.17	.00233	.00218	88	4	50	85	1.7	4.4	5.3	5.3	△
G1.0	1:5	0.71	0.00041	0.00035	71	4	48	103	1.3	3.1	4.1	4.2	⊙
G1.1		0.78	.00020	.00013	41	5	35	—	1.4	3.4	4.4	4.5	⊙
G1.2		0.85	.00029	.00022	139	4	41	—	1.5	3.7	4.8	4.8	⊙
G1.35		0.97	.00047	.00035	43	4	35	—	1.6	4.2	5.2	5.3	⊙
H1.0	1:5.6	1.00	0.00139	0.00122	39	5	41	—	1.5	4.2	5.4	5.5	△
H1.1		1.10	.00217	.00205	70	4	44	—	1.6	4.9	5.9	5.9	△
H1.2		1.21	.....	.00500	72	5	42	—	1.9	4.9	6.0	6.0	□
I1.0	1:4.7	0.84	0.00077	0.00070	114	5	36	—	1.4	3.9	5.1	5.2	△
I1.1		0.93	.00066	.00058	176	5	36	110	1.6	4.1	5.2	5.3	△
I1.2		1.01	.00151	.00138	125	5	43	—	1.8	4.5	5.7	5.8	△
I1.35		1.15	.00196	.00170	71	4	32	—	1.8	4.8	6.0	6.1	△
J1.0	1:4	0.72	0.00032	0.00028	9	4	43	—	1.2	3.2	4.4	4.6	⊙
J1.1		0.79	.00033	.00020	43	4	43	—	1.4	3.6	4.8	4.9	⊙
J1.2		0.86	.00044	.00035	14	4	43	—	1.5	3.9	5.0	5.1	⊙
J1.35		0.97	.00057	.00045	33	4	44	—	1.7	4.3	5.5	5.6	⊙
K1.0	1:6	0.74	0.00049	0.00040	50	4	40	86	1.3	3.2	4.1	4.2	⊙
K1.08		0.80	.00034	.00023	74	4	46	—	1.3	3.2	4.2	4.3	⊙
K1.16		0.86	.00059	.00050	40	4	41	—	1.4	3.4	4.4	4.5	⊙
K1.3		0.97	.00081	.00070	57	4	40	85	1.5	3.6	4.6	4.7	⊙
L1.0	1:5	0.74	0.00035	0.00026	115	5	44	—	1.2	3.1	4.2	4.3	⊙
L1.1		0.82	.00059	.00052	73	5	39	—	1.2	3.2	4.3	4.5	⊙
L1.2		0.89	.00059	.00042	90	5	38	85	1.3	3.5	4.7	4.8	⊙
L1.35		1.01	.00127	.00096	98	5	44	—	1.4	3.8	5.0	5.1	△
M1.0	1:6	0.88	0.00060	0.00046	30	5	39	—	1.3	3.4	4.4	4.6	⊙
M1.1		0.97	.00064	.00056	61	5	42	—	1.2	3.3	4.6	4.6	△
M1.2		1.07	.00136	.00122	64	5	40	—	1.4	3.7	4.8	4.9	△
M1.35		1.20	.00574	.00520	54	4	38	—	1.6	4.2	5.2	5.3	□

TABLE 8—RESULTS OF FLOW AND ABSORPTION TESTS—CONTINUED

Mark	Mix by Volume	Water-cement Ratio	Flow Tests: Flow in gal. per sq. ft. per hr. 20-50 hr. Interval	Flow Tests: Flow in gal. per sq. ft. per hr. 40-50 hr. Interval	Flow Tests: Max. Plus Variation from Aver. 40-50 hr. Flow, per cent	Flow Tests: No. of Specimens Tested	Flow Tests: Average Age in Days at First Testing	Flow Tests: Age in Days at Re-testing	Percentage of Absorption after: ½ hr.	6 hr.	24 hr.	48 hr.	
N1.0	1:5	0.74	0.00041	0.00034	18	5	39	380	1.2	3.1	4.0	4.1	⊙
N1.1		0.82	.00042	.00038	33	4	39	—	1.4	3.5	4.4	4.4	⊙
N1.2		0.90	.00066	.00052	92	5	41	95–480	1.5	3.8	4.8	4.8	⊙
N1.35		1.02	.00087	.00075	45	4	38	—	1.7	4.2	5.2	5.3	△
O1.0	1:7	0.98	0.....	0.00216	48	5	46	130–300	1.5	3.8	4.8	4.8	△
O1.1		1.09	.00433	.00408	72	5	42	90–150	1.7	4.2	5.0	5.1	□
O1.2		1.19	.00716	.00664	10	3	41	—	1.7	4.5	5.3	5.3	□
P1.0	1:6	0.89	0.00080	0.00058	55	5	36	—	1.4	3.4	4.5	4.5	△
P1.1		0.99	.00084	.00070	114	5	37	—	1.3	3.7	4.9	5.0	△
P1.2		1.09	.00127	.00105	60	4	41	—	1.4	4.0	5.3	5.4	△
P1.35		1.23	.00599	.00536	40	4	43	—	1.6	4.5	5.5	5.6	□
Q1.0	1:5	0.74	0.00039	0.00032	23	4	38	—	1.2	3.0	4.1	4.2	⊙
Q1.1		0.80	.00038	.00032	25	5	37	—	1.3	3.3	4.6	4.7	⊙
Q1.2		0.90	.00057	.00046	52	5	39	92	1.5	3.8	5.1	5.1	⊙
Q1.35		1.02	.00115	.00100	20	4	47	285	1.6	4.1	5.4	5.5	△
R1.0	1:4	0.64	0.00033	0.00028	135	5	37	—	1.2	2.8	3.8	4.0	⊙
R1.1		0.70	.00030	.00027	106	5	39	—	1.4	3.2	4.2	4.4	⊙
R1.2		0.77	.00093	.00070	100	5	39	77	1.4	3.5	4.7	4.8	⊙
R1.35		0.88	.00191	.00138	103	5	39	81–423	1.7	4.0	5.2	5.3	△
S1.0	1:6	0.92	0.00159	0.00132	67	5	38	—	1.4	3.6	4.8	4.9	△
S1.1		1.02	.00267	.00238	51	5	39	283	1.6	3.9	5.2	5.3	□
S1.2		1.12	.00229	.00190	63	5	38	330	1.6	4.4	5.7	5.7	□
S1.35		1.27	.01350	.01230	48	3	41	—	2.0	5.1	6.0	6.1	□
T1.0	1:5	0.79	0.00041	0.00034	47	5	38	—	1.3	3.4	4.7	4.9	⊙
T1.1		0.88	.00084	.00072	39	5	40	75	1.4	3.9	4.9	5.0	△
T1.2		0.96	.00094	.00072	67	5	40	75	1.5	4.1	5.2	5.4	△
T1.35		1.09	.00141	.00128	88	4	41	—	1.8	4.8	5.8	5.9	△
U1.0	1:4	0.69	0.00016	0.00008	150	4	41	—	1.4	3.4	4.4	4.5	⊙
U1.1		0.76	.00031	.00023	21	5	39	—	1.5	3.8	4.8	5.0	⊙
U1.2		0.84	.00049	.00042	67	5	40	—	1.5	3.9	4.9	4.9	⊙
U1.35		0.94	.00059	.00052	35	5	38	—	1.8	4.6	5.5	5.6	⊙
V1.0	1:6	1.02	0.00139	0.00115	124	4	39	—	1.5	4.2	5.2	5.3	△
V1.1		1.12	.00214	.00185	72	4	41	—	1.6	4.4	5.5	5.6	△
V1.2		1.23	.....	.00625	39	4	41	—	1.8	4.6	5.6	5.8	□
V1.35		1.38	.02600	.02430	48	3	45	115	2.0	5.0	6.0	6.1	□
W1.0	1:5	0.84	0.....	0.00070	71	4	41	—	1.2	3.4	4.7	4.8	⊙
W1.1		0.93	.00074	.00058	72	4	39	—	1.5	3.7	4.8	4.9	⊙
W1.2		1.01	.00141	.00116	81	5	38	—	1.5	4.0	5.3	5.4	△
W1.35		1.13	.00160	.00142	97	4	38	—	1.6	4.4	5.7	5.8	△
X1.0	1:4	0.66	0.00069	0.00056	61	5	40	—	1.2	3.0	4.2	4.3	⊙
X1.1		0.73	.00061	.00052	131	5	40	120	1.2	3.2	4.3	4.4	⊙
X1.2		0.80	.00059	.00048	150	5	40	120	1.3	3.6	4.7	4.8	⊙
X1.35		0.90	.00073	.00062	158	5	39	—	1.6	4.3	5.3	5.4	△
Y1.0	1:5	0.77	0.00105	0.00092	74	5	46	—	1.2	3.2	4.3	4.4	△
Y1.1		0.84	.00065	.00048	67	5	40	—	1.4	3.7	4.7	4.8	⊙
Y1.2		0.92	.00078	.00064	88	5	38	—	1.4	3.7	4.8	5.0	△
Y1.35		1.04	.00122	.00106	60	5	48	330	1.6	4.2	5.4	5.5	△

TABLE 8—RESULTS OF FLOW AND ABSORPTION TESTS—CONTINUED

Mark	Mix by Volume	Water-Cement Ratio	Flow Tests						Percentage of Absorption after				
			Flow in gal. per sq. ft. per hr.		Max. Plus Variation from Aver. 40-50 hr. Flow, per cent	No. of Specimens Tested	Average Age in Days at First Testing	Age in Days at Re-testing	½ hr.	6 hr.	24 hr.	48 hr.	
			20-50 hr. Interval	40-50 hr. Interval									
Z1.0	1:7	0.87	0.00153	0.00122	23	4	39	—	1.3	3.2	4.0	4.2	◬
Z1.1		0.96	.00222	.00186	223	5	40	120	1.2	3.3	4.4	4.4	◬
Z1.2		1.05	.00239	.00200	130	4	44	120	1.3	3.5	4.5	4.6	◬
Z1.35		1.19	.00565	.00522	72	4	50	—	1.4	3.7	4.6	4.7	⊡
a1.0	1:6	0.77	0.00088	0.00072	67	5	43	—	1.1	2.8	3.9	4.1	◬
a1.1		0.83	.00115	.00086	51	5	44	—	1.3	3.3	4.3	4.3	◬
a1.2		0.93	.00082	.00058	38	4	47	—	1.4	3.5	4.4	4.4	⊙
a1.35		1.04	.00157	.00140	50	4	46	110	1.5	3.7	4.6	4.7	◬
b1.0	1:7	1.02	0.00189	0.00162	172	4	37	—	1.2	3.4	4.3	4.5	◬
b1.1		1.12	.00407	.00358	37	4	40	—	1.4	3.9	4.6	4.6	⊡
b1.2		1.23	.....	.00436	47	5	44	—	1.5	4.2	4.8	4.8	⊡
d1.0	1:6	0.87	0.00106	0.00084	43	5	36	—	1.3	3.4	4.2	4.2	◬
d1.1		0.96	.00145	.00118	95	4	37	—	1.4	3.6	4.5	4.6	◬
d1.2		1.05	.00166	.00140	29	4	35	100	1.5	4.0	4.8	4.9	◬
d1.35		1.18	.00552	.00470	143	5	41	188–450	1.6	4.2	4.9	4.9	⊡
e1.0	1:5	0.76	0.00042	0.00030	133	5	36	—	1.3	3.2	4.2	4.2	⊙
e1.1		0.84	.00051	.00044	127	5	37	—	1.3	3.3	4.3	4.4	⊙
e1.2		0.92	.00069	.00050	80	5	37	105	1.4	3.6	4.5	4.5	⊙
e1.35		1.04	.00164	.00138	38	4	41	—	1.6	4.0	4.8	4.8	◬
f1.0	1:4	0.67	0.00021	0.00015	62	5	39	100	1.3	3.0	3.9	4.0	⊙
f1.1		0.73	.00019	.00012	61	4	37	—	1.3	3.2	4.2	4.3	⊙
f1.2		0.80	.00029	.00018	47	4	37	—	1.4	3.4	4.4	4.5	⊙
f1.35		0.90	.00079	.00066	52	5	36	215	1.5	3.8	4.8	4.8	◬
g1.0	1:7	1.07	0.00346	0.00310	94	4	35	196	1.5	3.9	4.8	4.8	⊡
g1.1		1.18	.00579	.00546	71	5	45	—	1.6	4.4	5.2	5.2	⊡
g1.2		1.29	.00719	.00658	70	4	38	85	1.7	4.6	5.3	5.3	⊡
h1.0	1:6	0.93	0.00265	0.00212	65	5	37	—	1.4	3.8	4.8	4.9	◬
h1.1		1.02	.00232	.00188	92	5	46	90	1.6	4.4	5.1	5.2	◬
h1.2		1.11	.00346	.00316	58	5	37	—	1.6	4.5	5.3	5.3	⊡
h1.35		1.25	.00965	.00902	38	4	43	—	1.9	4.9	5.4	5.4	⊡
k1.0	1:5	0.80	0.00075	0.00062	61	5	36	—	1.3	3.6	4.7	4.8	⊙
k1.1		0.88	.00059	.00042	90	5	36	—	1.5	4.0	5.1	5.1	⊙
k1.2		0.96	.00053	.00040	25	5	36	—	1.5	4.0	4.9	4.9	⊙
k1.35		1.08	.00134	.00116	98	5	37	95	1.7	4.4	5.2	5.3	◬

Addenda for Table 8.

Column 8—"Average Age in Days at First Testing" includes age of rerun specimens when age at retest was less than 75 days.

Column 9—"Age in Days at Retesting" includes age of rerun specimens when more than 75 days old.

Explanation of Symbols.

⊙ Surface dry, but greater flow than wetter mix.

⊙ Surface dry.

◬ Surface somewhat wet.

⊡ Surface quite wet.

TABLE 9—DENSITIES, CEMENT-VOIDS RATIOS AND OTHER PHYSICAL CONSTANTS FOR MIXES

Mark	Mix by Volume	Water-Cement Ratio	Density	Absolute Vol. of Cement per Unit Vol. of Concrete	Cement-Voids Ratio	Cement-Space Ratio	Cement-Dry Agg. Ratio by Weight
A1.0	1:7	0.97	0.844	0.0719	0.464	0.316	0.108
A1.1		1.07	.834	.0711	.429	.300	
A1.2		1.18	.825	.0703	.401	.286	
B1.0	1:6	0.89	0.837	0.0817	0.503	0.334	0.126
B1.1		0.96	.833	.0814	.489	.328	
B1.2		1.05	.823	.0804	.453	.312	
B1.35		1.20	.816	.0797	.434	.302	
C1.0	1:5	0.73	0.836	0.0963	0.590	0.370	0.151
C1.1		0.81	.828	.0953	.556	.357	
C1.2		0.90	.823	.0948	.537	.349	
C1.35		1.01	.818	.0941	.518	.341	
D1.0	1:4	0.63	0.838	0.1175	0.728	0.421	0.190
D1.1		0.66	.833	.1167	.697	.411	
D1.2		0.74	.822	.1152	.647	.393	
D1.35		0.81	.819	.1147	.632	.387	
E1.0	1:7.1	1.02	0.829	0.0698	0.408	0.290	0.107
E1.1		1.09	.828	.0697	.405	.288	
E1.2		1.15	.830	.0698	.411	.291	
F1.0	1:6	0.85	0.840	0.0822	0.515	0.340	0.126
F1.1		0.95	.835	.0817	.496	.331	
F1.2		1.04	.828	.0810	.471	.320	
F1.35		1.17	.821	.0804	.450	.310	
G1.0	1:5	0.71	0.839	0.0964	0.598	0.374	0.151
G1.1		0.78	.835	.0960	.581	.367	
G1.2		0.85	.825	.0949	.543	.352	
G1.35		0.97	.817	.0939	.514	.339	
H1.0	1:5.6	1.00	0.810	0.0791	0.419	0.294	0.126
H1.1		1.10	.801	.0782	.394	.282	
H1.2		1.21	.795	.0777	.382	.275	
I1.0	1:4.7	0.84	0.812	0.0933	0.497	0.331	0.151
I1.1		0.93	.810	.0931	.490	.328	
I1.2		1.01	.800	.0919	.460	.314	
I1.35		1.15	.797	.0916	.451	.311	
J1.0	1:4	0.72	0.818	0.1078	0.595	0.372	0.177
J1.1		0.79	.807	.1064	.552	.355	
J1.2		0.86	.803	.1060	.539	.350	
J1.35		0.97	.794	.1047	.510	.337	
K1.0	1:6	0.74	0.850	0.0800	0.536	0.349	0.121
K1.08		0.80	.849	.0798	.528	.345	
K1.16		0.86	.842	.0792	.501	.334	
K1.3		0.97	.841	.0791	.497	.332	
L1.0	1:5	0.74	0.847	0.0937	0.611	0.379	0.145
L1.1		0.82	.839	.0929	.579	.366	
L1.2		0.89	.830	.0919	.542	.351	
L1.35		1.01	.820	.0908	.506	.336	
M1.0	1:6	0.88	0.835	0.0787	0.476	0.322	0.121
M1.1		0.97	.831	.0785	.465	.317	
M1.2		1.07	.824	.0777	.441	.306	
M1.35		1.20	.816	.0770	.420	.296	

TABLE 9—DENSITIES, CEMENT-VOIDS RATIOS AND OTHER PHYSICAL CONSTANTS FOR MIXES—CONTINUED

Mark	Mix by Volume	Water-Cement Ratio	Density	Absolute Vol. of Cement per Unit Vol. of Concrete	Cement-Voids Ratio	Cement-Space Ratio	Cement-Dry Agg. Ratio by Weight
N1.0	1:5	0.74	0.836	0.0929	0.565	0.361	0.147
N1.1		0.82	.831	.0924	.548	.354	
N1.2		0.90	.826	.0918	.529	.345	
N1.35		1.02	.821	.0912	.509	.337	
O1.0	1:7	0.98	0.842	0.0694	0.439	0.305	0.105
O1.1		1.09	.834	.0687	.414	.293	
O1.2		1.19	.822	.0678	.381	.276	
P1.0	1:6	0.89	0.837	0.0791	0.484	0.326	0.122
P1.1		0.99	.829	.0784	.460	.315	
P1.2		1.09	.821	.0777	.435	.303	
P1.35		1.23	.812	.0768	.409	.290	
Q1.0	1:5	0.74	0.837	0.0937	0.576	0.365	0.147
Q1.1		0.80	.834	.0934	.564	.360	
Q1.2		0.90	.818	.0916	.503	.334	
Q1.35		1.02	.812	.0909	.483	.326	
R1.0	1:4	0.64	0.834	0.1138	0.689	0.407	0.185
R1.1		0.70	.828	.1130	.660	.397	
R1.2		0.77	.818	.1116	.615	.380	
R1.35		0.88	.805	.1098	.564	.360	
S1.0	1:6	0.92	0.827	0.0782	0.452	0.311	0.122
S1.1		1.02	.822	.0777	.438	.304	
S1.2		1.12	.813	.0769	.411	.291	
S1.35		1.27	.800	.0756	.377	.274	
T1.0	1:5	0.79	0.828	0.0921	0.534	0.348	0.146
T1.1		0.88	.823	.0915	.517	.340	
T1.2		0.96	.813	.0904	.483	.326	
T1.35		1.09	.803	.0895	.455	.312	
U1.0	1:4	0.69	0.827	0.1114	0.644	0.391	0.182
U1.1		0.76	.815	.1099	.595	.373	
U1.2		0.84	.811	.1093	.579	.366	
U1.35		0.94	.798	.1076	.533	.347	
V1.0	1:6	1.02	0.810	0.0774	0.407	0.289	0.123
V1.1		1.12	.805	.0768	.395	.283	
V1.2		1.23	.797	.0760	.374	.272	
V1.35		1.38	.789	.0754	.358	.263	
W1.0	1:5	0.84	0.814	0.0913	0.493	0.330	0.148
W1.1		0.93	.811	.0906	.479	.324	
W1.2		1.01	.805	.0903	.464	.316	
W1.35		1.13	.799	.0896	.446	.308	
X1.0	1:4	0.66	0.823	0.1123	0.635	0.388	0.184
X1.1		0.73	.816	.1113	.607	.377	
X1.2		0.80	.810	.1105	.584	.368	
X1.35		0.90	.801	.1093	.571	.355	
Y1.0	1:5	0.77	0.821	0.0960	0.536	0.349	0.155
Y1.1		0.84	.816	.0955	.517	.341	
Y1.2		0.92	.808	.0946	.492	.330	
Y1.35		1.04	.801	.0938	.474	.321	
Z1.0	1:7	0.87	0.853	0.0685	0.468	0.319	0.102
Z1.1		0.96	.852	.0685	.464	.316	
Z1.2		1.05	.850	.0683	.458	.313	
Z1.35		1.19	.842	.0678	.430	.300	

TABLE 9—DENSITIES, CEMENT-VOIDS RATIOS AND OTHER PHYSICAL CONSTANTS FOR MIXES—CONTINUED

Mark	Mix by Volume	Water-Cement Ratio	Density	Absolute Vol. of Cement per Unit Vol. of Concrete	Cement-Voids Ratio	Cement-Space Ratio	Cement-Dry Agg. Ratio by Weight
a1.0	1:6	0.77	0.855	0.0796	0.551	0.355	0.120
a1.1		0.83	.847	.0788	.516	.340	
a1.2		0.93	.841	.0782	.491	.329	
a1.35		1.04	.834	.0776	.469	.319	
b1.0	1:7	1.02	0.843	0.0667	0.425	0.298	0.101
b1.1		1.12	.836	.0662	.405	.288	
b1.2		1.23	.831	.0657	.390	.280	
d1.0	1:6	0.87	0.842	0.0763	0.485	0.326	0.117
d1.1		0.96	.843	.0765	.489	.328	
d1.2		1.05	.835	.0757	.459	.314	
d1.35		1.18	.830	.0752	.443	.306	
e1.0	1:5	0.76	0.844	0.0900	0.578	0.366	0.140
e1.1		0.84	.840	.0896	.561	.359	
e1.2		0.92	.836	.0892	.545	.352	
e1.35		1.04	.825	.0880	.502	.334	
f1.0	1:4	0.67	0.840	0.1094	0.684	0.406	0.176
f1.1		0.73	.833	.1086	.651	.394	
f1.2		0.80	.826	.1075	.619	.382	
f1.35		0.90	.813	.1060	.568	.362	
g1.0	1:7	1.07	0.834	0.0650	0.392	0.281	0.099
g1.1		1.18	.831	.0648	.383	.276	
g1.2		1.29	.825	.0643	.367	.268	
h1.0	1:6	0.93	0.839	0.0751	0.467	0.318	0.115
h1.1		1.02	.834	.0746	.449	.310	
h1.2		1.11	.836	.0748	.458	.313	
h1.35		1.25	.822	.0735	.415	.292	
k1.0	1:5	0.80	0.839	0.0882	0.550	0.353	0.138
k1.1		0.88	.836	.0879	.537	.349	
k1.2		0.96	.828	.0872	.509	.336	
k1.35		1.08	.822	.0865	.487	.327	

TABLE 10—RESULTS OF FLOW TESTS AT 100 LB. PER SQ. IN. PRESSURE

Mark	Flow in gal. per sq. ft. per hr.		Maximum Plus Variation from Average Flow in per cent		No. of Spec. Tested	Age in months	Condition of Surface
	40-50 hr. Interval	100-110 hr. Interval	40-50 hr. Interval	100-110 hr. Interval			
D1.0	0.000325	0.00016	54	128	3	11	dry
D1.35	.00070	.00045	114	167	5	16	dry
F1.1	.00022	.000175	127	71	4	12	moist
G1.1	.00030	.000175	100	69	5	10	moist
H1.0	.00185	.00140	130	115	5	11	moist
L1.0	.00040	.00020	20	50	5	15	dry
L1.1	.00104	.00060	83	66	5	14	dry
P1.0	.00080	.00060	60	58	5	14	moist
Q1.0	.00050	.00025	100	...	5	14	dry
R1.0	.00032	.00010	50	54	5	14	dry
R1.35	.000184	.00017	180	114	4	15	moist
S1.2	.00480	.00400	73	120	5	14	wet
T1.1	.00090	.00065	66	85	5	14	moist
U1.2	.00075	.00050	48	68	5	14	moist
W1.2	.00212	.00112	53	145	5	14	moist
X1.0	.00092	.00050	47	60	5	15	moist
X1.35	.00110	.00045	63	189	5	15	dry
Y1.2	.00100	.00049	75	125	5	15	moist
Y1.35	.00200	.00140	112	50	5	15	moist

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F. R. McMillan and Inge Lyse. *Some Permeability Studies of Concrete.* JOURNAL A. C. I., December, 1929. Discussion ibid April, 1930.
F. R. McMillan. *Basic Principles of Concrete Making.*

Readers are referred to the JOURNAL *for November, 1931 (V. 28), for discussion which may develop. Such discussion should reach the Secretary by Oct. 1, 1931.*

Discussion of three Papers under the general heading:*

Workability and Admixtures

"A Study of the Flow Table and the Slump Test"
BY GEORGE A. SMITH AND SANFORD W. BENHAM

"A Study of Slump and Flow of Concrete"
BY INGE LYSE AND W. R. JOHNSON

"Admixtures and Workability of Concrete"
BY G. M. WILLIAMS

The discussion here presented based on three closely related and previously published papers was led by R. B. Young and J. C. Pearson, selected by the Program committee to present convention discussion, in an effort at some reconciliation of view of a moot subject. The impromptu convention discussion; the written discussion prior and subsequent to the convention, is so voluminous as to exceed available space in this Journal. *It is therefore continued to the* Journal *for November, 1931, (Vol. 28) and the publication of several interesting contributions already available is necessarily deferred.*—Editor

BY R. B. YOUNG

I understand that I was chosen to introduce this discussion on the basis that I am a disinterested party, which might be interpreted to mean that I do not know anything about it and therefore am a safe speaker. After reading the papers, I am less prejudiced than I was before because I know less about the subject than I did before. The papers are conflicting and I have been unable to comply with the specification and bring them together. The papers by Mr. Smith and Mr. Benham, and Mr. Lyse and Mr. Johnson, both report experimental comparisons of the flow table and slump as measures of workability and con-

*The three papers were discussed at the 27th Annual Convention, Milwaukee, February 24-26, subsequent to publication in this Journal: "A Study of the Flow Table and the Slump Test," by George A. Smith and Sanford W. Benham, January, 1931, Vol. 27, p. 420. "A Study of Slump and Flow of Concrete," by Inge Lyse and W. R. Johnson, January, 1931, V. 27, p. 439. "Admixtures and Workability of Concrete," by G. M. Williams, February, 1931, Vol. 27, p. 647.

sistency, using similar materials and proportions but different methods of approach. They have arrived at almost opposite conclusions as far as the main point is concerned. I have spent some time trying to bring these two papers together and I have not been very successful, because the fact remains that they record—and I am unable to find a reason why—such different conclusions. It seems to me, after studying the methods and test data obtained, that the data are unconvincing and the reasonable conclusion is that neither is the measure of the workability. Workability, as I believe most men handling concrete will agree, is that combination of the properties of concrete which allow us to handle and place it with reasonable labor and minimum segregation. Neither the slump test nor the flow test measures this property. The slump test has been used as a control test in the field for a great many years, and its widespread adoption is proof of its merit for the purpose. Smith and Benham point out that the slump test acts differently with different types of mixtures. They state this: "During the making of the tests four characteristic conditions as to general shapes of the resulting slump specimen were observed. First; specimens slumped only small amounts and retained somewhat the same shape as the molded sample. Second; specimens slumped several inches but held together, bulging out uniformly as the slump took place." That is the ideal condition when it is used as a control work. "Third; a portion of the specimen stood up on one side and the remainder fell away; not a usual condition and always checked by a second trial. Fourth; top slushed down, leaving a mound, generally of compacted aggregate in the center." That is, the concrete had begun to segregate. The observations of this paper have been quite the general experience of most users of this test. The principal value of the slump test is its use with a certain class of concrete where a uniform degree of workability is represented by a given slump. With fixed materials and a fixed combination of those materials, you can represent the workability that you are after by some slump and later you can be fairly certain that the concrete from which the sample was taken has a workability close to what you are after, if it has that same slump, but if you change the conditions, using other materials possibly, it will take another degree of slump to represent the same degree

of workability. As a control test, that idiosyncrasy of the slump is not so important. However, when it comes to measuring workability and the effect of admixtures, those little peculiarities make it difficult to interpret the result.

The flow test is almost entirely a laboratory test and is not subject to the same faults as the slump test, but is usable over a greater range of mixtures. Its principal value has been to define the approximate workability of a mix in laboratory work. There again I would say that if you find in one of these discussions, that the investigator has had a flow of 80, another laboratory worker has a good idea of what that mixture looks like, but beyond giving the other investigator an idea of what the concrete looks like, I think the test has little practical use. It is entirely too cumbersome for a practical field test.

To increase the range of mixtures, the investigators reporting in these two papers have introduced admixtures into their tests. While the purpose was to increase the range of mixtures studied, I think that one of the most likely results will be to add a good deal of discussion to the papers. In fairness to the authors, I think it should be pointed out that none of them is presenting his data to make a case for or against admixtures. These two papers present studies at workability and tests of workability, and, as I read the papers, the introduction of admixtures was more or less incidental. I think that neither the slump test nor the flow test can be safely used to determine the value of admixtures in concrete, and I, for one, would not accept any conclusions based thereon.

The paper by Professor Williams presents a new method of approach to the study of workability and the value of admixtures. In submitting his data, he made the following comments, which are worth reading. They give a little different slant to his subsequent discussion, if his viewpoint is taken into account. The author writes:

> My purpose was to outline a method of test for the rating of admixtures rather than to discuss the merits or demerits of any particular one or group. A satisfactory test should be established first. Had I intended to compare the admixtures in this manner, I would have included several others which have been used commercially, one of them approaching fairly near to No. 6 in efficiency. I included a minimum of test data in tabular form to make com-

parisons easier. Strength, porosity and permeability must be taken into account in any final rating of an admixture, but I felt that to discuss these factors at length would only divert attention from the test methods proposed, toward the admixtures themselves. The statement that admixtures "do not appreciably affect strength or permeability when used in the amount or proportion specified by the manufacturer" briefly sums up any discussion which I might make in connection with these factors.

Professor Williams discusses in his paper certain fundamental facts. He compares cement and admixtures as to the volume of paste given when equal weights are mixed to give pastes of equal flow; also, the effect on the volume of mortar under the same conditions and the effect on preventing segregation when jigged, and then proceeds to demonstrate the reasonableness of his method of study by producing a series of concretes which were alike in their tendency to segregate when made up as suggested by his previous tests. In closing his paper, he takes a very sane view of the possible uses and abuses of admixtures, which I will quote in closing:

While admixtures are relatively more efficient than cement in obtaining a concrete of workability suited to any given condition of transportation and placement, the writer does not suggest that their use is always necessary or advisable. For concrete of any required cement content first attention should be directed to the most desirable sand-gravel ratio. Relative increase in sand content increases mortar volume which in turn permits the use of a less fluid mortar, thereby increasing workability and postponing likelihood of segregation. After adjusting the sand-gravel ratio and finding segregation under the conditions of use, or that the mix is near the segregation limit the use of an admixture will be advantageous. In work where a surface as true as the face of the mold is desired or in any case where the available fine aggregate is coarse and harsh, lacking in fine particles, the use of an admixture may be of value in obtaining satisfactory results.

The factors of strength and watertightness should not be forgotten. Generally these properties cannot be sacrificed to obtain workability. Tests which the writer has made quite definitely indicate that admixtures do not appreciably affect strength or permeability when used in the amounts or proportions specified by the manufacturer. In cases where excess quantities of an admixture are needed to produce satisfactory workability the possibility of reduction in strength and watertightness must receive consideration. On the basis of workability alone, the data in Table 1 would indicate the use of an admixture to be dependent mainly upon the relative cost of cements and admixtures. The use of admixtures 2 to 5 would not be economical unless their cost were less than twice, and No. 6 less than five or six times, the cost of portland cement. Consideration should also be given to the fact that cement not only increases workability as an admixture but at the same time it definitely increases strength and impermeability.

BY J. C. PEARSON

These valuable papers on slump and flow tests ought to be considered about the last word on the subject. They represent a very large amount of careful and painstaking work—how large can only be adequately realized by those who have studied the data closely. There are many interesting details worthy of attention, but this writer begs the privilege of departing from the usual custom, and of confining himself to a discussion of the present status of the workability problem and of the possibilities that are suggested by the data in the papers, and by certain experiments which have been carried out in the Research Laboratory of the Lehigh Portland Cement Co.

The outstanding feature of the papers by Smith-Benham and Lyse-Johnson is the demonstration that for concretes of different composition the ratio of slump to flow as measured on the flow-table is not constant, but increases with the richness of the mixtures. The significance of this important fact can be brought out on certain assumptions, if we consider briefly the characteristics of plastic materials.

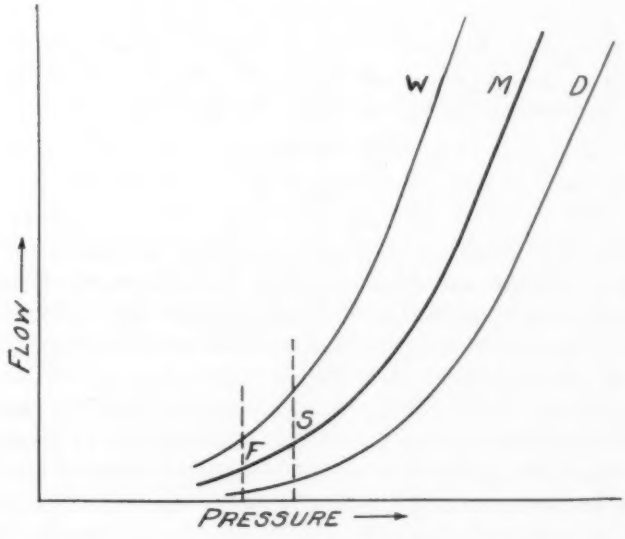


FIG. 1

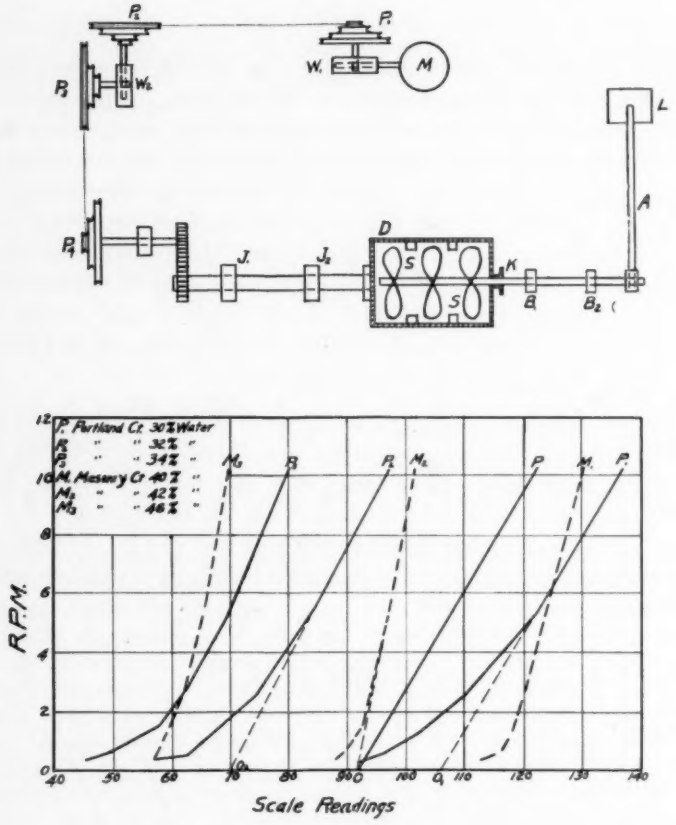


FIG. 2

If a mass of freshly mixed concrete could be forced out of a container through an orifice or a tube in such manner that the rate of shearing flow could be determined under different pressures we should expect to find the flow-pressure relations represented by a curve like one of those in Fig. 1. Confining ourselves for the moment to the heavy curve, M, we see that at first, for slight or moderate pressures, there would be no flow at all; at somewhat higher pressures the flow would be sluggish, but increasing with increase in pressure; and finally after the pressure had reached a certain value the relation of flow to pressure would become linear, or approximately so. I am not aware that an experiment of this

kind has ever been carried out successfully with concrete, but the relation is a typical one for plastic materials, and we have quite a lot of data substantiating the assumption that the relation holds for concrete.[1] The slope of the straight-line portion of the curve is commonly referred to as the "mobility," and we have found from a study of cement pastes that this factor of mobility is the one which seems most nearly allied to, and best adapted for, a comparative plasticity rating.

The upper portion of Fig. 2 illustrates a device used in our laboratory for studying the flow-force relations in cement pastes. A mixer drum, D, is mounted on the end of a stout shaft supported in the bearings J_1, J_2, and is driven by means of gears, belts, step pulleys, reducing units and a small constant speed motor, M. By simply changing the position of the belts the drum may be driven at 12 different speeds. Projecting into the drum through a low-friction packing gland, K, is another shaft supported in ball bearings, B_1, B_2, and blades or paddles, S, of different types, may be mounted on the shaft inside the drum. The outer end of this shaft carries a rigidly clamped arm, A, the far end of which rests on a platform balance, L. When the drum is filled with paste and put in rotation the blades, S, shear through the paste, and a certain resistance is set up by them which is indicated on the balance, L. Thus we have a system for measuring flow-force relations in which the speed of the drum is analagous to the rate of flow, and the reacting torque of the stator blades is the force.

Some typical results obtained with this device are shown in the lower portion of Fig. 2. The curves P_1, P_2, and P_3 were obtained from portland cement pastes containing different amounts of water; the curves M_1, M_2 and M_3 were obtained from masonry cement pastes containing different amounts of water. What I wish to call attention to particularly in this figure is the fact that change in the water content of the pastes shifts the curves to the right or left on the diagram with only a slight change in their slopes. This slight change in slope enables the interpolation of a curve with an intermediate slope, such as the line OP, which may be compared directly with the slope of the line OM_2, having the same intercept on the pressure axis. Now we believe that when

[1]Purrington & Loring obtained curves of this general type for concrete by measuring the power input and speed of a mixer. See A. S. T. M. Proceedings Vol. 30, Pt. II, p. 654-667, 1930.

two pastes are compared in this manner, the one which gives the greater slope, that is, the one which has the higher mobility, is the more plastic. The physical significance of this is that if one paste is more plastic than another, it shears more easily and flows more readily than the other when it is mixed in a pan or spread with a trowel. Furthermore, experience indicates that this property of the paste is carried over into mortars and concretes, and the degree of it that manifests itself depends upon the quantity of the paste in proportion to the aggregates, and also to a greater or less extent upon other factors, such as the grading of the aggregates, the presence of admixtures, etc.

This presentation is already familiar to some of you who are members of A. S. T. M. Committee C-9, but I have gone into the matter of these paste tests in some detail because of its direct bearing on the question under discussion. Returning now to Fig. 1, we may show why the flow and slump tests function as they do, under certain assumptions. The effective force that produces flow in a mass of concrete on a flow table is small, corresponding to a low pressure value on the diagram. The point F on the typical curve M may be taken to represent the region in which the flow table operates, corresponding to a relatively small deformation in the concrete. In the slump test the effective force tending to cause subsidence of the cone corresponds to a somewhat higher value on the diagram, represented, let us say, by the abscissa of the point S. Now in a given mixture, as shown above for pastes, moderate change in water content would be expected to shift the curve to the left (for wetter consistency), or to the right (for drier consistency), and the change in flow would be roughly proportional to the change in slump, as shown in Smith and Benham's Fig. 8, or in Lyse and Johnson's Figs. 5 to 8. That the change in slump should be more sensitive than the change in flow is also clearly indicated from the relative lengths of the ordinates through F and S and included between the curves W and D.

It has been shown in Fig. 2 that what we may call the intrinsic plasticity of a mixture (meaning that part contributed by or characteristic of the solids) is indicated by the steepness of the flow-pressure curve. Hence if we have different concretes

varying from lean to rich, or from harsh to plastic, and gage them to the same flow on the flow table, their flow-pressure curves will be somewhat as represented in Fig. 3. The point F represents the

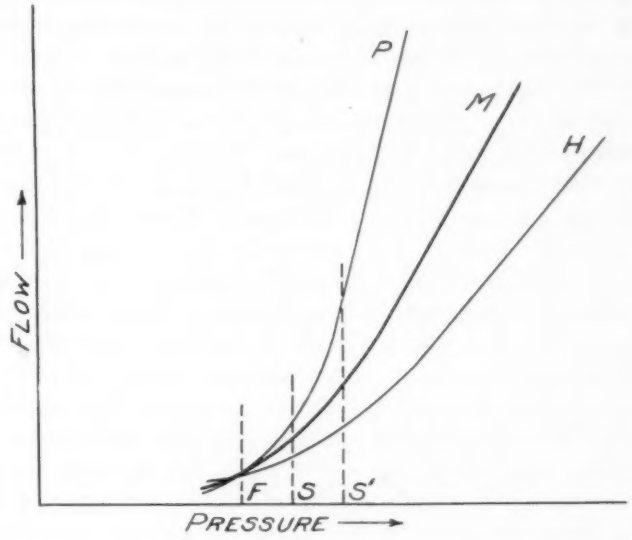


FIG. 3

force applied in the flow table test, at which point all have the same flow; the point S represents the force applied in the slump test, and it is evident at once that the plastic concretes should slump more than harsh concretes, just as the tests reported in these papers have shown.

The point of all this is that no single measure of "consistency" can possibly tell the whole story, as W. H. Herschel has so frequently insisted in his A. S. T. M. discussions[1] of papers on this general subject. If the slump test were not so crude and so lacking in dependable reproductibility, we could, as Lyse and Johnson have so ably pointed out, get some notion of relative plasticity by careful comparisons of flow-table and slump tests. But the slump test greatly needs improvement to bring about reasonable reproducibility. A complete mechanization of the

[1]See A. S. T. M. Proceedings, Vol. 25, Pt. II, p. 216, 1925; Vol. 28, Pt. II, p. 522, 1928; Vol. 29, Pt. II, p. 871, 1929.

test might help considerably, and we should be in a still better position if we could devise a more effective device, such for example as would yield the higher flows corresponding to the abscissa S′ in Fig. 3. Obviously the more points that can be obtained in these flow-pressure curves, the more certain we shall be of the characteristics of the mixtures studied.

This discussion is not intended to be discouraging to those who are interested in the practical problem of consistency control. A moderately improved slump test or a simplified flow test will serve this purpose very nicely. But for those who are interested in finding out how the workability of different mixtures can be compared and improved economically without sacrifice of other essential qualities, and what part admixtures and aggregate gradings and types contribute to this property, no single test will suffice. The ideal scheme would be to have some device that would furnish a number of well-defined points on these flow-pressure curves, but up-to-date we have found no satisfactory scheme of handling a batch of concrete in such way as to measure both force and rate of flow. Failing in this we have attempted to improve on the slump test, in the hope of using the improved test in connection with the flow-table, and thus getting two fairly definite points on the curves. But to date we have failed to overcome an undesirable lack of reproducibility, which is one of our main objections to the slump test.

The more we ponder upon this problem, the more likely it seems to us that some comparatively simple device will be developed, by means of which two or more definite applications of force can be applied to a mass of concrete, and the corresponding rates of flow measured, at least in relative terms. Perhaps we will make more progress if we deliberately turn our backs upon the present slump and flow tests and keep our thoughts focused on those fundamental relations that we want to bring out.

BY G. A. SMITH*

First I wish to consider the subject of workability of concrete in a general way. I do wish, however, to point out that, at the time our paper was presented, the sole purpose was to show that the slump test and the flow test, both used to measure the same

*Convention presentation by George A. Conahey.

property or condition of concrete, namely wetness, do not function to give comparable results. Since there was a lack of correlation in results as the mix was varied, there is conclusive evidence to the effect that other properties of the concrete were having some influence on the values obtained. I hope to take up this phase of the subject later in a separate discussion of the paper by Messrs. Lyse and Johnson.

Prof. Williams has brought out a very interesting point in the consideration of workability. Though I agree with him that segregation plays a large part when studying the property, workability, I believe that it is only one factor influencing the placeability of concrete.

First, what do we mean by workability? I am of the opinion that this involves much more than a simple consideration of the condition of the fresh concrete. In order that concrete may be of service it must be placed in the forms. For the service rendered to be of the highest quality, it is necessary that the ingredients of the concrete be uniformly distributed throughout the member. Were it possible to place concrete without effort so that a uniform and homogeneous member would result there would be no need to consider the question of workability or let us say placeability. The fact remains that concrete cannot be placed to give a satisfactory finished structure without the expenditure of effort. When I say satisfactory finished product I do not mean one which an unscrupulous artisan would pass, but one that comes as near being perfect as it is possible to make it. Uniform distribution of ingredients, complete filling of all intricate parts of the mold, and freedom from open porous structure, are conditions that must be fulfilled in the satisfactory product.

Since effort must be spent in placing concrete, be it supplied by man power, or otherwise, it is an item of cost and must be given its proportion of consideration. The amount of effort required is variable depending on the character of the concrete and the condition under which it is being placed. For example, rich mixes are recognized as being more workable than lean mixes. Concrete suitable for reinforced members is usually too wet for constructing roads, and 6-in. cobbles which are entirely satisfactory in massive structures would result in anything but a workable concrete where intricate steel fabrication and relatively

small members are concerned. Suitability for the purpose intended makes the question of workability a relative one, as Prof. Williams points out but there is ever present the fact that under all conditions work must be done to effect satisfactory placement.

Abstractly any mass of material may be workable but one may be more workable than another depending upon the amount of effort or work necessary to accomplish a definite end. In the case of concrete any mass of concrete can be worked or placed but the amount of work necessary to effect a given condition in the final product differentiates between two mixes as to their relative workability. The mass that can be placed with the least effort will be the most workable.

When placing concrete it is necessary to move small parts of the mass to remove entrained air and effect a satisfactory placement. This presupposes a non-segregating mix. In the case of a segregating mix though the concrete may fill the form fairly readily and without material effort there enters the question of distribution of the materials. If segregation has occurred, it means that a large amount of effort must be expended to bring about a redistribution of the ingredients if the satisfactory structure is to result. The remixing in the forms may be so arduous a task that it is not accomplished and the result is an inferior product. The additional work required in the case of a segregating mix may be much more than that in a mix apparently less easily worked but relatively non-segregating.

To my mind the term workability involves the question of the amount of work necessary in placing the concrete to accomplish a satisfactory finished product. On this basis segregation destroys the homogeneity of the mix and necessarily contributes to a non-workable condition requiring more work to bring about the condition we desire. The workability of a concrete, therefore, is the resultant of two factors: (1) The ease with which the aggregate particles and small parts of the concrete mass may be moved relative to each other, and (2) Cohesion within the mass or lack of segregation.

The ease, under a given condition of placement, with which movements within the mass are accomplished is dependent on the size, shape and surface characteristics of the aggregate particles and the quantity, quality and characteristics of the medium in

which they are distributed. Cohesion or lack of segregation is dependent on the same factors as those influencing the ease of movement but they do not always function in the same direction to affect the amount of work necessary to place the concrete. For example, increasing the quantity of cement, consistency and other conditions remaining constant, increases both the ease of movement and cohesion within the mass. On the other hand increasing the quantity of mixing water increases the ease of movement under a condition of uniform distribution but decreases the cohesion.

There is no need to enumerate the various items incident to the manufacture of concrete that influence workability. Each and every condition has its effect. Most of these have been discussed before this Institute and any further discussion would be superfluous. The question of admixtures and their functioning, appears to be a major consideration for this discussion. This phase I wish to discuss briefly, not with the view of comparing various admixtures but to point out what an admixture may do to improve conditions.

In any design certain conditions are laid down and under these it is expected that the requirements for the job will be met. Any addition of material to the designed mix which will influence the placeability or workability in a beneficial way may be deemed an admixture. This may be additional cement, increased quantity of mixing water, a combination of the two or some other material of merit. Should any change be made by such additions there are two conditions that must be met: (1) the quality of the resulting concrete must be unimpaired. (2) The workability of the concrete should be so improved that the placing may be expedited and result in a superior finished product.

It is generally conceded that added cement has a beneficial effect on the workability and we, not infrequently hear of an additional sack of cement being used because of its effect. The answer to this is not difficult. Since cement in reasonable amounts is necessary for a moderate degree of workability, increasing the cement paste in quantity and quality, consistency or wetness remaining constant, the ease of displacement and the cohesion in the mass are increased.

Water used to increase workability is a most unreliable admixture. Though a certain amount is necessary, depending on the job conditions, any quantity in excess of this amount is injurious to the finished product and may go so far as to cause a negative result so far as workability is concerned. Displacement in a plastic mix may be more difficult than in a wet mix but lack of cohesion in the wet mix results in segregation and additional work to effect satisfactory placement.

Other materials to be added to a mix, normally thought of as admixtures, should function to increase the ease of placement and to improve the condition of the finished product. Some materials are more effective to this end than are others just as one cement may result in a more workable concrete than another. It was pointed out that both ease of movement within the mass and segregation were dependent on the quantity, quality and characteristics of the cement paste and characteristics of the aggregates. Since the aggregates are inert, admixtures would not have any effect on them as such. The only phase they can influence is that of the cement paste.

The addition of any finely divided material and the addition of the necessary water to maintain a constant consistency tend to increase the volume of the paste. This increase in the volume of paste permits a wider separation of the aggregate particles and a consequent reduction in the resistance to internal movement. Plastic properties of the paste and concrete mass as a whole may be improved depending on the characteristics of the admixture used. Reference has been made to the fat, smooth condition noticed in concrete containing some admixtures. This condition, since it parallels that observed when the richness of a mix is increased, not only increases the ease of internal movement but also decreases segregation by increasing the cohesion within the mass.

The advantages to be derived from improving workability though not always tangible are nevertheless real. Expediting the placement and overcoming unsightly honey combing which requires patching are tangible enough in themselves but the effect of non-uniform distribution of materials which affects the durability and stability of a structure are not always apparent until it is too late to remedy matters.

It is hoped that this discussion may be helpful in bringing about a unification of ideas relative to the property, workability, so that before long when the term is used we may each have a more clear cut idea of what is meant.

The fact that the value of workability is appreciated leads me to the belief that, eventually, it will be analyzed and that a full and complete understanding will be reached.

Someone may ask the question; How is the property to be evaluated? To evaluate the property and put it on a mathematical basis would require some means for measuring the work necessary to effect satisfactory placement. Numerous attempts have been made toward this end and, if they have shown nothing more, they indicate that under comparable conditions concretes of different compositions have different properties so far as the placeability is concerned. This is an every day observation in the laboratory. When casting specimens it is observed that more effort is required to rod one concrete than is required for another. This is brought about by variation in the distribution and the resistance of the mass to the penetration of the rod. Though differentiation between mixes when rodding is at times an easy matter, it is only a relative condition that is noted and the measurement is purely qualitative. I believe that an evaluation of the rodding effort would come as near being a measure of the property as anything that could be devised. In fact this is the basic idea back of the penetration apparatus. I have used this apparatus in studying the effects of numerous admixtures and the effects of varying the proportions, grading, consistency, etc., and have obtained indices for the workability which appear to parallel interpretation as to the relative workability of the concretes considered.

In conclusion I wish to say that, with the extensive thought and consideration now being given to this phase of concrete it is my firm conviction we will not have to wait long for an answer to some of our problems. We will have in the near future a definite correlation of ideas on the subject and an accepted method of evaluating separately, if not collectively, the two factors governing workability namely, ease of movement in the mass and segregation.

DISCUSSION OF LYSE AND JOHNSON PAPER BY G. A. SMITH

The editorial comment introducing the two papers, one by Messrs. Lyse and Johnson on the subject of the consistency of concrete and the other by Mr. Benham and the writer, creates an erroneous impression relative to the attitude of the several authors. The comment indicates that the writer favors the flow-table as a yardstick for measuring workability whereas Messrs. Lyse and Johnson favor the slump test. I wish to point out that in no instance in the paper "A Study of the Flow-Table and the Slump Test" was the flow-table indicated as a measure of workability. The authors certainly did not at any time have in mind indicating that either test is a measure of workability when concretes of different compositions are considered. When referring to the property or condition that was being measured the terms consistency and wetness were used.

Though the workability of *a given mix* will vary, within limits, with the quantity of water used or with the wetness as indicated by either the slump or the flow, the workabilities of two different mixes gaged to either the same slump or to the same flow may be entirely different. The point is, that workability and wetness (consistency) are not synonymous under all conditions. In this case the use of the two conditions or properties interchangeably leads to a misunderstanding and a misrepresentation of the authors' conclusions. I quote from the last paragraph of the conclusions: "The data on the whole indicate that, where a consistent indication of the consistency or wetness of concrete is desired, the flow test is preferable to the slump test because of its more nearly uniform functioning." The only condition indicated is *consistency* or wetness.

The Editor in introducing the two papers asks, who can discover a common ground. It appears to me that both papers have very much in common and when properly interpreted will indicate the same conditions and that the same conclusions may be reached from either paper.

It was with a great deal of pleasure and interest that I reviewed the paper "A Study of the Slump and Flow of Concrete." Particularly because Messrs. Lyse and Johnson showed tendencies of results where conditions were comparable that paralleled those

observed from our tests. No comment is necessary in these instances. On the other hand there are one or two conditions on which I wish to comment.

The authors indicate that the use of the slump specimen in determining the flow results in larger flows and consequently is a more sensitive measure than is the flow obtained with the usual flow mold. This is quite obvious but it has little to do with the apparatus or the condition of the concrete. It is largely a question of mathematics. Consider the conditions existing in the test. The volume of concrete in the flow specimen is about 0.16 cu. ft. and the basic diameter is ten inches. In the slump specimen there is approximately 0.20 cu. ft. of concrete and the basic diameter is eight inches. Other conditions being equal it is seen that the flow increase in diameter with the slump specimen should be about 1.6 times as great as that using the flow specimen. There is, however, the effect of the additional head and that of the erratic functioning of the slump test which tends to give a greater spread. The increased head due to the height of the slump specimen does not appear to have a large effect since the ratio of the increase in flow for the slump specimen to that for the flow specimen between the zero and the five drops (Figs. 1, 2 and 3) varies from less than 1.0 to 1.7 averaging less than 1.3. Were the functioning consistent the increase in flow would be about 1.6. The functioning of the slump test has been discussed in the paper by Mr. Benham and the writer. It was pointed out that in the wetter mixes the concrete flowed down and out and the test was not a true slump. In the tests by Lyse and Johnson this same condition undoubtedly existed as is evidenced by the high flows at zero drops and was unquestionably responsible for at least a part of the increased flow observed. Personally, the writer is inclined to favor flows of lower magnitude because of the more nearly rectilinear relation that exists between flow and the quantity of water used. After the mass of concrete has spread a certain amount this relation no longer exists but becomes a curvilinear relation since the area covered by the sample varies as the square of the diameter. No specific example can be cited but it is readily seen that during the early flow there is a reserve supply of sample which is apparently used up in compensating

for the increased area. After this reserve has been used and the concrete has spread to nearly uniform thickness proportionate changes in diameter become less for increased manipulation and for additional quantity of mixing water. This is evidenced by the diminished rate of flow with increased number of drops for the wetter consistencies, (See Figs. 1, 2 and 3 of Lyse and Johnson paper) as well as lowered increased in flow for a given increase in water.

Lyse and Johnson make numerous references throughout the discussion and in their conclusions to the effect that the slump test is superior to the flow test for measuring workability. This is based on the observation that for a given flow the slump for the richer and more workable mixes was greater than that for the less workable mixes. The variation in slump with observed improvement in workability, the flow being constant, was observed and pointed out by the writer.

It is believed that the difference in slump, flow or consistency or wetness being constant does parallel improvement in workability. However, to say that, because of this, the slump is superior to the flow as a measure of workability is far from being logical. Let us consider the converse of this condition of equal flows and variable slumps. For equal slumps and flow would be less for the more workable mixes. It would be, then, just as logical to say that the flow was a more sensitive measure of workability, the workability varying inversely as the difference in flow.

Neither test in itself can be used as a criterion. Supposing that either the slumps or the flows were constant for two mixes, one lean and the other rich. The fact that the slumps were constant according to the authors would indicate that one was equally as workable as the other. This we know is not the case. Each of the methods is a measure of the wetness or consistency of the concrete and individually for a given mix is a measure of the relative fluidity of the mix. The only correlation between slump or flow and workability is in the case of a given mix. With a variation in quantity of water both the slump and the flow vary and so does the workability within limits. Mixes varying in proportions with variable materials cannot be correlated as to

relative workability by either of the test methods used independently.

In conclusion I believe that the Editor's question has been answered and that we find far more in common in the two papers than there is in disagreement. There is one differentiation that must be made relative to two properties of concrete. Under different conditions of composition and under variable conditions as relate to the properties of the separate ingredients of concrete, it is absolutely necessary to distinguish between fluidity, wetness, consistency or whatever we choose to call it and the workability. Once this is done we will be in a position to study the effects various materials and variations in materials have on the workability or the placeability of concrete.

BY DONALD M. BURMISTER*

These two papers are valuable contributions to the study of concrete mixtures and contain very complete data showing the variation of slump and flow resulting from changes in cement and water content in various concrete mixes. The interpretation of the data by the writer leads to the conclusion that these tests measure different properties of the concrete mixtures, both of which, however, must be included in any criteria for workability. In the following discussion the writer presents a study of these data and suggests a means of combining the test results in order to arrive at a measure involving both properties of concrete.

The handling and placing properties of concrete may be expressed in two ways, first on the basis of the effort and time to produce the finished product, and second on the basis of observed effects of certain characteristics by which workability may be judged. The properties of concrete are reflected in varying degrees in its behavior in every test made upon it as well as upon the job. Its more or less fluid nature imparts flow characteristics. Its semi-plastic nature imparts smoothness and mobility. These two qualities together determine to a large extent the workability of concrete. These qualities as criteria of workability in concrete may be used as bases of design of concrete mixtures or of the comparison of concretes.

In order to evaluate the slump and flow tests, it is necessary to determine how these two tests function and which qualities of

*Instructor in Civil Engineering, Columbia University. His discussion was presented at the Convention by title only.

a concrete mix have the greater relative effect, for which that test then may be taken as a relative measure.

The flow table—Primarily the flow table brings out the fluidity of the concrete due to wetness. Flow is a property of a fluid condition. A more or less true flow is produced by the work performed upon the concrete when the mass has been broken down or has slumped down, so that a quite uniform slope exists radially outward from the center.

This is indicated in Fig. 1, 2, and 3, by Messrs. Lyse and Johnson, who have plotted in the lower right hand quarter of each figure the effect of the number of ½-in. drops of the flow table upon the flow, using the flow cone. The effect of some slumping action in increasing the flow from zero to five drops is shown in nearly every case by the greater steepness of the curves in this range. Thereafter the curves assume an almost uniform slope, showing that the flows for successive drops were very nearly equal, and were proportional to the work performed upon the concrete. Therefore a better measure of wetness is obtained by the larger number of drops, for instance ten or fifteen.

It seems to the writer that a better and more sensitive measure of wetness is obtained by using that half of the circumference of the concrete mass, on which the greatest flow occurs as the average figure. The lopsided flow, if the flow cone has been properly centered, is an exaggerated condition, due mainly to non-uniformity of depositing the concrete. But this condition may reflect a harshness and a tendency toward segregation in the concrete. The uniform slope of the curve mentioned above and the almost regular increase in flow with increase in wetness shows that the flow table measures the wetness of concrete.

The slump cone—The slump cone measures primarily the plasticity of a concrete, which is imparted to the mass by the fine material in the mortar, whether it be cement, silt and clay, or other admixtures. The differences in the properties and the behavior of workable concretes and those classified as non-workable are largely due to this fine material, which acts as a lubricant and more important still tends to retain all of the mixing water within the mass. Consequently smoothness and mobility are imparted to the concrete, which varies with the amount and the kind of this fine material and also with the amount of mixing water.

In plastic concrete the particles of coarse aggregate, when separated by sufficient plastic mortar, flow more smoothly over one another than in a non-plastic harsh one, because of the low shearing resistance. Consequently the mass as a whole deforms more readily. Therefore under the action of gravity the plastic concrete will slump more for the same degree of wetness.

The slump cone gives a real measure of this quality plasticity only when a true slump is obtained as indicated in types 1 and 2 by Messrs. Smith and Benham. If type 4, in which the concrete slushes down leaving a compacted core, indicates anything, it shows that there has been a breakdown in the binding properties of the mortar, due to an excess of mixing water in relation to the given mix. There will therefore be a greater tendency for segregation and for the leaking of the liquid from the concrete.

In these two tests two qualities have been relatively measured, or rather the effects of these two qualities:

1. The flow table reflects the wetness of the concrete.

2. The slump test reflects the plasticity of the concrete. Of course in both tests both qualities have some effect, but the nature of the tests are such as to bring out the particular quality more effectually.

A method of relatively evaluating the effects of these characteristics of concrete is outlined, resulting in the plasticity coefficient, which is suggested by the writer as an index or yardstick of relative workability. For any given concrete the plasticity coefficient is the ratio of the slump in inches to the inches of radial flow on the flow table.

The Plasticity Coefficient equals $\frac{\text{Slump in inches}}{\text{Radial flow in inches}}$. It reflects the relative plasticity and wetness of the concrete and is indicative of the behavior of concrete during handling and placing. The purpose of such an index is to provide a figure which will be indicative of the characteristics, and one which may be used as a basis of comparison and design of concretes, which the slump or flow alone have not effectually done. The properties and behavior of any concrete are made more tangible and the concrete is more completely defined by:

1. The plasticity coefficient and the flow. or

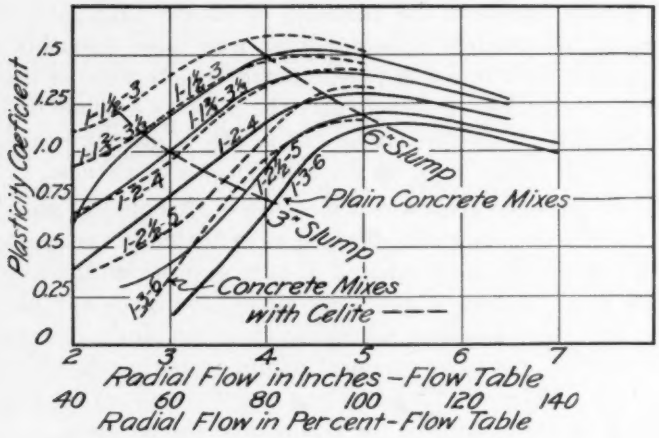


FIG. 1—RELATIONS OF PLASTICITY COEFFICIENT, FLOW AND MIX

2. The plasticity coefficient and the slump.

When the curves in Fig. 8, "Relation between Flow and Slump" by Messrs. Smith and Benham are replotted with the plasticity coefficient as ordinates and the corresponding flows for the different mixes as abscissas, a most interesting set of curves results. The flow is chosen rather than the slump because the

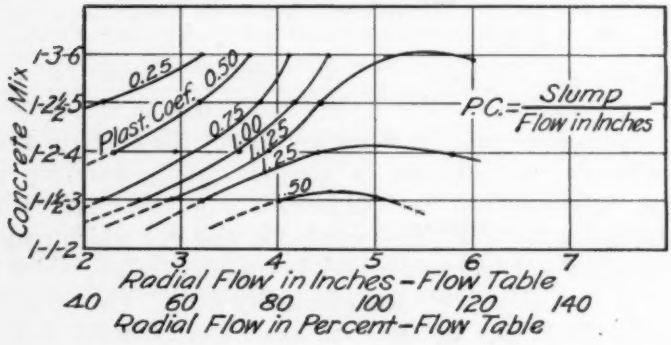


FIG. 2—THE VARIATION OF THE PLASTICITY COEFFICIENT WITH FLOW FOR PLAIN CONCRETE

range is greater and the curves bring out certain facts better. A flow of 100 per cent on the flow cone of ten inches in diameter, for instance, corresponds to a radial outward flow of five inches, and others in proportion. The data taken from these curves is tabulated in Tables 1 and 2.

These results have been plotted in Fig. 1, showing the relation of the plasticity coefficient, flow and mix. They have been replotted from the curves of Fig. 1 in a different form in Fig. 2, which brings out better the relations existing between these factors.

The following conclusions are obtained from these curves.

1. The plasticity coefficient increases with the richness of the concrete. A high plasticity coefficient, as a criterion of the desirable qualities of concrete, is indicative of a uniform and homogeneous product with little tendency to segregate.

2. The plasticity coefficient also increases with the addition of water up to some maximum point, which is the limit of workability for that concrete. However, this maximum point probably results from the fact that the slump test ceases to function as such for slumps greater than seven inches.

3. The addition of Celite as an admixture increases the plasticity coefficient, and that for a given flow concrete with Celite admixture has the equivalent plasticity coefficient of a much richer mix, as indicated by the relative positions of the curves, thus indicating an increase of workability.

4. The two figures plasticity coefficient and flow or slump are quite definitely indicative of the relative ease with which a concrete may be handled and placed, and are therefore bases for the comparison of concretes, as to their handling and placing properties.

5. A low plasticity coefficient either indicates lean watery concrete which is harsh and will tend to segregate badly, or it indicates a very dry harsh mix which is difficult to place. Any considerable working to make such concretes flow into form work will only aggravate its undesirable tendencies.

6. In Fig. 1 two lines have been plotted showing the relation of slumps of 3 and 6 in. to both the plasticity coefficient and flow. These show that for equal slumps the leaner mixes are much wetter and more fluid than the richer mixes as indicated by their

respective flows, and also the plasticity coefficients are lower for the leaner mixes. Considering equal flows, the richer mixes have greater slumps and the greater plasticity coefficients, and there-

DATA TAKEN FROM FIG. 8, "RELATION BETWEEN FLOW AND SLUMP" BY GEORGE A. SMITH AND SANFORD W. BENHAM

TABLE 1

Flow		Plasticity Coefficients for Plain Concretes									
Per Cent	Radially in Inches	1:3:6 Slump	1:3:6 Pl. C.	1:2½:5 Slump	1:2½:5 Pl. C.	1:2:4 Slump	1:2:4 Pl. C.	1:1⅔:3⅓ Slump	1:1⅔:3⅓ Pl. C.	1:1½:3 Slump	1:1½:3 Pl. C.
40	2.0					.8	.40	1.3	.65	1.2	.60
50	2.5			.8	.30	1.4	.56	2.0	.80	2.5	1.00
60	3.0	.5	.17	1.3	.43	2.3	.77	3.0	1.00	3.5	1.17
70	3.5	1.4	.40	2.2	.63	3.4	.97	4.2	1.20	4.8	1.33
80	4.0	2.7	.68	3.7	.93	4.7	1.17	5.4	1.35	6.0	1.50
90	4.5	4.6	1.02	5.2	1.15	5.7	1.26	6.3	1.40	6.8	1.50
100	5.0	5.6	1.12	5.9	1.18	6.4	1.28	7.0	1.40	7.4	1.47
110	5.5	6.2	1.13	6.5	1.18	7.0	1.28	7.4	1.35	7.9	1.43
120	6.0	6.6	1.11	6.9	1.15	7.4	1.23	7.8	1.30	8.3	1.39
130	6.5	6.7	1.03	7.2	1.11	7.7	1.19	8.0	1.25	8.4	1.19
140	7.0	7.0	1.00	7.3	1.05	7.8	1.11				

TABLE 2

Flow		Plasticity Coefficients for Concretes with Celite Admixture									
Per Cent	Radially in Inches	1:3:6 Slump	1:3:6 Pl. C.	1:2½:5 Slump	1:2½:5 Pl. C.	1:2:4 Slump	1:2:4 Pl. C.	1:1⅔:3⅓ Slump	1:1⅔:3⅓ Pl. C.	1:1½:3 Slump	1:1½:3 Pl. C.
40	2.0					1.3	.65	1.8	.90	2.2	1.10
50	2.5			1.2	.48	2.0	.80	2.7	1.08	3.0	1.20
60	3.0	1.0	.33	1.7	.57	2.8	.93	3.6	1.20	4.3	1.40
70	3.5	2.3	.66	2.7	.77	4.1	1.17	4.8	1.37	5.4	1.55
80	4.0	3.8	.95	4.4	1.10	5.3	1.33	5.9	1.48	6.4	1.60
90	4.5	5.2	1.13	5.8	1.31	6.3	1.40	6.7	1.48	7.2	1.60
100	5.0	6.0	1.20	6.5	1.30	7.0	1.40	7.3	1.46	7.7	1.54
110	5.5	6.5	1.18	7.0	1.27	7.4	1.31	7.8	1.42	8.2	1.49
120	6.0	6.8	1.15	7.3	1.21	7.7	1.28	8.1	1.32		
130	6.5	7.0	1.08	7.4	1.15	7.8	1.20	8.3	1.28		
140	7.0	7.2	1.03	7.7	1.10	8.0	1.14	8.4	1.20		

Note—Pl. C. is the Plasticity Coefficient

fore possess more of the desirable qualities by which workability is judged.

7. Similar curves for other materials will reflect the effect of grading and proportions upon the workability of the concrete made from them.

Basis of comparison—In classifying a concrete it may be more plastic and less wet or it may be wetter and less plastic. Any real basis of comparison must rest upon measures of both of these characteristics in concrete. The two concretes are quite different in their properties and behavior and are judged accordingly as to their relative workabilities. From the foregoing discussion it is seen that there are two bases of comparison of concretes, that are quite definite and simple of application.

1. The comparison of plasticity coefficients for equal flows.

2. The comparison of plasticity coefficients for equal slumps. The ones with the greater plasticity coefficients have more of the desirable qualities by which workability in concrete is judged.

Basis of design—From the design standpoint there are two simple requirements which can be specified in addition to the water-cement ratio governing strength.

1. A minimum value for the plasticity coefficient consistent with the class of concrete and the field conditions.

2. A maximum flow or slump suitable for the given field conditions.

In meeting these requirements a concrete of pretty definite characteristics and uniformity is obtained. In this connection the curves in Fig. 2 are very useful, or similar ones. For example, if a flow of 70 per cent or 3½ inches on the flow table was desirable and suitable for the given field conditions and further if a plasticity coefficient of at least 1.00 was specified, the leanest mix that could be used for the given materials and proportions of aggregates would be a 1:2:4 plain concrete. The necessary slump that must be obtained is readily found from the relation—
Slump equals Pl. C x Flow in inches.

This simply means that the concrete has the desired properties and workability for the given job, when the flow is 3½ in. and when the slump is also 3½ in. at the same time. To meet both criteria at the same time in a concrete mix is to ensure the quality specified, whether obtained by the use of more cement,

admixtures, or better by such gradings and proportions of the aggregates as are necessary. This may be accomplished by trial methods, starting with a cement paste of given water-cement ratio, as specified for strength. When the mix has been properly designed, using both tests to fix its characteristics, then the proper field control may be maintained by means of the slump test alone, as an indication of the uniformity of the output.

Thus by combining the results of the flow table and the slump tests, the properties and behavior of any concrete are made more tangible and the criteria of plasticity coefficient and flow or slump serves as a more definite basis for designing concrete mixtures and for the comparison of different concretes.

BY F. O. ANDEREGG

The method of attack on the workability problem proposed by Mr. Pearson of using the pressure-flow rate curve is, I believe, the best that has so far been suggested. After seeing these curves it is obvious why the slump result may not be consistent with the flow table finding. It should be pointed out, however, that the flow rate is usually linear while both slump and flow table measure flow in two dimensions.

The best definition of workability involves both ease of working the concrete into place and freedom from segregation. The latter is a result of improper grading somewhere in the system: The water may flow from the cement if the latter is not properly ground; the cement paste may have a tendency toward oozing out of the sand if the latter is improperly graded; and finally, the mortar and coarse aggregate may separate from each other.

By building up a system with a proper gradation of sizes we have in the first place a sort of filter which prevents segregation. It is a little like a sand filter except that here we want a system where large particles serve as a sort of anchor or key holding back the next smaller size and so on down to the finest cement particles. In turn all the smaller sizes act as ball bearings permitting the ready rolling of the next larger into place.

The result is a maximum of ease of placing, a minimum of segregation, together with a maximum of packing and very good workability is secured with a minimum of lubricating water.

To secure this ideal grading use a set of Tyler standard screens differing in opening dimension by the factors and the ratio of fractions on the separate sieves is constant at about 1.2, the increase in weight (or absolute volume) being greater as the sizes increase. This ratio is affected slightly by the shape of the particles.

On a basis of the ideal grading we can go ahead logically with the analysis of the workability of commercial concretes. The latter differ from the ideal by gaps in the grading curve, or humps where too great a preponderance of one size occurs, or in combinations of the two. The procedure would then be to determine complete pressure-flow rate curves at several degrees of wetness for ideally graded materials and then introduce systematically humps and gaps into the curve, and determine the effect. When sufficient experience has been accumulated, one should be able to predict accurately what any given commercial grading will do and give it a grade, say 50 per cent or 70 per cent of the ideal.

On a basis of an ideal grading it is not difficult to secure an understanding of the role of *admixtures*, other than specific waterproofing materials or hardeners. If the cement is not ground to approximate the ideal (and few cements are in the very fine region) a finely ground, well-graded admixture may aid in filling voids and serving as ball-bearings. In this way a real improvement may be made.

Again, if the aggregates are quite harsh it is necessary to provide a greater bulk of paste to prevent segregation and containing more lubricating water. With bentonite clays and diatomaceous earths we can get more lubricating water into the system. At the same time the water-cement ratio is increased and whether the addition effects an all-around improvement depends upon the grading curve for the whole system, cement-sand-coarse aggregate. With properly ground cement and properly graded aggregate an admixture would be not only superfluous, but actually harmful.

FURTHER DATA WITH DISCUSSION FROM G. M. WILLIAMS

The writer has not at this writing seen the discussion relating to his paper "Admixtures and Workability of Concrete" but some of the criticisms and questions may be partially answered

by the following data obtained in tests with a type of admixture which was not represented in the original tests.

The writer's definition of workability and the effect of admixtures is summarized as: By workability is meant the ability of a concrete mixture to remain homogeneous and free from segregation during the process of transportation and placement. A non-segregating mix, having necessary flowability, is a workable mix. Segregation is influenced by quality and quantity of mortar in the mix and occurs when mortar is so fluid that it cannot adhere to the large aggregate particles and hold them in suspension, or when the relative mortar content is too small. Workability increases and segregation decreases as volume of mortar increases which results in a heavier, stickier, better adhering mortar without loss of necessary flowability. Various powdered admixtures including portland cement, were found effective in increasing relative mortar volume but their efficiencies varied greatly. The efficiencies were approximately proportional to the volumes of pastes formed when equal weights of admixtures were brought to the same flowabilities. Identical concretes containing equal volumes of admixture pastes were found to result in practically the same segregations as measured by spread of aggregate beyond the mortar line in the flow table.

While one admixture used in the original tests contained a percentage of bentonite or colloidal clay its behaviour was not the same as has been found for Colloy and Aquagel, two colloidal clays which are representative of this type. While some work has been done with both of these materials the data following relates mainly to the use of Colloy as an admixture to increase workability.

Colloidal clays or bentonite have the property of absorbing many times their weight of water, resulting in the formation of a very large paste volume. When used as an admixture in concrete a large increase in mortar volume should be expected, due to the addition of a relatively small weight of the material in powder form. Volumes of pastes formed by the addition of water up to 300 per cent by weight are shown for Colloy, Aquagel and Celite in Fig. 1. This water quantity is just beyond the saturation limit for Celite. It will be noted that the volumes are practically the same and proportional to water content up to this limit.

Comparing Celite and Colloy identical concretes were prepared to which were added equal weights of admixtures. Flowabilities were made equal, amount of segregation noted, and mortar volumes computed as listed in Table 1.

TABLE 1—AVERAGE MORTAR VOLUMES AND AMOUNTS OF SEGREGATION FOR EQUAL WEIGHTS OF ADMIXTURES

Weight of Admixture grams	Volume Mortar c. c.	Increase in Mortar Volume due to Admixture c. c.	Added Mixing Water Required by Admixture grams	Segregation of Coarse Aggregate grams	Flowability
0	763	...	...	197	177
48 Colloy	821	58	38	148	174
48 Celite	883	120	100	41	175

As indicated in Table 1 the large volume increase in mortar content which would be expected for Colloy did not result. The foregoing figures indicate that approximately 100 grams of Colloy would be needed under these conditions of test to furnish a mortar volume resulting from the use of 48 grams of Celite.

In Table 2 are shown the results when the Colloy content was adjusted to furnish the same mortar volume.

TABLE 2—AVERAGE MORTAR VOLUMES AND AMOUNTS OF SEGREGATION ADMIXTURES PROPORTIONED FOR EQUAL MORTAR VOLUMES

Weight of Admixture grams	Mortar Volume c. c.	Segregation of Coarse Aggregate grams	Mixing Water c. c.	Flowability
100 Colloy	886	36	390	172
48 Celite	885	22	400	180

In the foregoing experiments the Colloy was added in dry powder form with the other constituents, as is the usual practice and as is recommended by the producer of this admixture. In no case, when this procedure was followed, was it possible to obtain the bulking effect for Colloy which would be expected from a study of Fig. 1. Similar results were also found for Aquagel.

However, when the admixture was pre-hydrated, by the formation of a paste prior to its addition to the volume of concrete, mortar volumes were increased in a manner which were considerably greater than could be predicted from Fig. 1. Results obtained by the two methods of adding the admixture are given in Table 3.

TABLE 3—COMPARISON OF MORTAR VOLUMES AND SEGREGATIONS OBTAINED WHEN COLLOY WAS ADDED AS (1) POWDER AND (2) A PASTE

Admixture	Total Mixing Water c. c.	Flow-ability	Volume Mortar c. c.	Segre-gation grams
48 Colloy (Powder)	365	192	840	100
48 Colloy (Paste)	565	187	1000	15

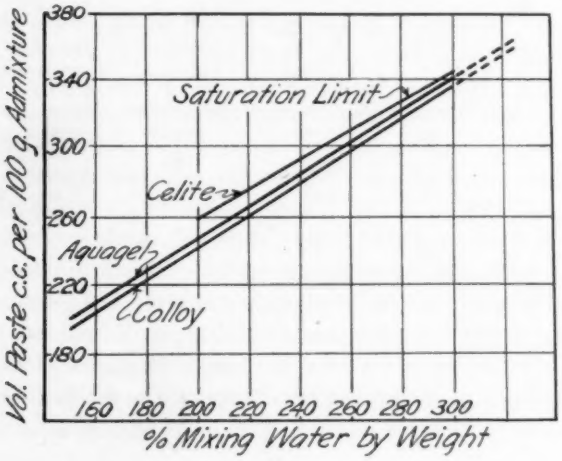


FIG. 1

The use of prehydrated Colloy resulted in the use of a greater total quantity of mixing water than was needed when the dry powder was added and in turn the mortar volume was greatly increased. The fact that some segregation occurred in spite of the large mortar volume in the batch, indicates this mortar to have lost some of its adhesiveness and power to hold the aggregate particles in suspension. The density or specific weight of this mortar must be less since water furnishes increase in volume, the solid content being the same.

The foregoing test results indicate that conclusion No. 2 of the original paper cannot be readily applied to admixtures of the bentonite type. Increase in volume with increase in water content in paste form is not a criterion of volume increase when the admixture is added to the concrete batch in the usual manner. If an admixture of the bentonite type is prehydrated before

addition to the mix its effect on mortar volume can be predicted from the volume of paste formed but this paste, due to its high water content, cannot be as efficient as one formed by the other types of admixtures, when compared volume for volume. The neat paste test will also fail in application to admixtures of the oil or tar type. Therefore it seems best to make use of the flow table segregation test directly in rating admixtures. Volume of paste formed is a matter of computation, and efficiency of the mortar in retaining and holding aggregate particles can be measured quantitatively by noting segregation. If mortars are dissimilar as may be the case in comparing a bentonite mortar with a Celite mortar, admixture quantities can be adjusted until the segregation is the same before decision as to relative efficiencies is made. In this manner the flow table segregation test can be employed to determine the efficiency of any admixture, whatever its type, and the procedure outlined above and in the original paper may be summarized as follows:

Step No. 1—Prepare a basic mixture of cement, graded sand and ¾-in. to ⅜-in. aggregate with the latter in excess so that when sufficient water is added to result in a non-fluid or segregating mortar (a plastic, adhesive mortar) there will be considerable segregation of coarse aggregate beyond the mortar line of the flow table.

Step No. 2—In addition to a basic mix plain concrete, prepare an additional batch for each admixture to be tested. Use specified quantities of admixtures and sufficient mixing water to result in the same flowability for all. Compute mortar volume of each batch and note the amount of segregation. Values obtained should be an average of at least three trials in which concordant results are obtained.

Step No. 3—Adjust admixture contents so as to furnish equal mortar volumes for each. Make flowabilities equal, compute mortar volumes and note segregations. After three concordant trials, if segregations are not approximately equal, further adjust admixture contents until equal segregations are obtained. Mortars lacking in density and adhesiveness to hold aggregate particles in the mass can be improved by the addition of more admixture in the case of powdered materials, which in turn tends to furnish a less fluid mortar of still greater volume without loss

of necessary flowability. Some adjustment of water content must be made with any change in admixture content when using materials of the powder type. In making the flow and segregation test particular care should be employed to insure uniformity in placement of concrete in the mold since those aggregate particles in the outer portion of the mass appear as segregated particles. Pockets of excess coarse material placed in the center of the mass will furnish too small segregation volumes and lead to improper conclusions.

Readers are referred to the JOURNAL *for Nov. 1931 (Vol. 28) for further discussion. All additional discussion should reach the Secretary by Oct. 1, 1931.*

Discussion of Report of Committee 108

"Properties of Mass Concrete"*

BY RAYMOND E. DAVIS†

The published report in the January Journal, is preliminary. I should like here to emphasize some of the things touched upon in the report and perhaps bring to your attention informally, certain other considerations, not previously presented. What I have to say will be more concerning what we do not know about mass concrete than what we do know. As a matter of fact, we know very little. Committee 108 was organized last spring because some of us felt the time had come to find out what is actually going on inside of concrete in large masses. The committee has done very little except to survey the field. The report presents a digest of material which has been gotten together by the committee giving available information which has been collected on various projects, principally in the field. The data have to do principally with dams—to some extent with other structures such as bridges and massive foundations. In examining the material, you will find that practically all of it has to do with the temperatures that have been observed to occur inside of these structures. We all know that cement and water, when mixed with aggregates to form concrete, evolve heat during the hardening process. In our small structures of thin sections, we do not notice that heat; but in the more massive structures, it becomes an important factor. We know something of the properties of concrete when cured at normal temperatures in small masses; but we do not know very much about the properties of concrete when cured at higher temperatures in large masses. Observations

*A. C. I. Journal, January 1931; *Proceedings*, Vol. 27, p. 385.

†Remarks by Professor Davis in formal presentation of his previously published Committee report to the 27th Annual Convention, Milwaukee, February 24-26, 1931. Following the Committee Chairman's introduction is the discussion, which will be continued in the Journal for November, 1931, V. 28.—Editor

made on various structures, even of the leaner concrete, show increases of temperature to 40 and 50 deg. above normal, or above the initial temperature of the concrete at the time of placing. With richer concrete we sometimes get increases of more than 100 deg.—in fact, in some cases, the cement paste boils. We have been taking it for granted that properties observed in concrete in small masses—properties of strength, elasticity, plasticity, durability, permeability—are to be found also in concrete of large masses, when, in point of fact, we do not know. To learn what we do not know in this regard is the job that faces our committee.

In the few tests made here and there in laboratories, notably some of the tests we have been making during the last couple of years, at the University of California, where we have specimen sizes up to one cubic yard, we have learned something of what happens to the strength under the temperature conditions that obtain inside the larger masses. We know that heat hastens the chemical process of hardening, and that at the early ages we get very much greater strength than at the normal standard temperature of 70 deg. But we know that concrete cured at the lower temperature gradually increases in strength until it passes that obtained with the higher temperatures that obtain inside the mass. In some cases there is a slight indication that there is a retrogression of strength when cured at the very high temperature. This Committee hopes to determine, both by laboratory tests and by field investigation, what is happening in our concrete structures and what are the properties of concrete cured in masses or under conditions simulating mass concrete. After concrete is placed, in a dam, for example, there is evolution of heat and the temperature rises. It continues to rise until the rate of heat evolution equals the rate of dissipation of heat, when the temperature curve, if you please, flattens out, becomes horizontal, and thereafter there is a gradual decline. In some of these structures the concrete does not come back to normal temperature until several years after placement. What are the stress conditions inside the structure? Certainly during the evolution of heat and increase in temperature there has been a tendency to expansion along the axis of the dam and then there is a compression, the concrete is then more or less in a plastic

state. It flows, if you please. When finally the peak has been reached, it is perhaps in a maximum state of compression, but thereafter, with the decline in temperature, there, a tension takes place before it gets back to normal temperature, and that may produce cracking, not only in the direction up and down stream, but perhaps along the axis of the dam itself, vertical cracks which in themselves may be very dangerous. Instead of a dam acting as a cantilever sticking up there, it might be acting as a succession of cantilevers, one leaning on the other like a pile of boards, and we might have a collapse.

Now the course of investigation would seem to be, first of all, to find a cement which would not evolve any heat, if such a thing were possible. While that is not possible, we are directed to a desirability of a cement with low heat evolution; perhaps a type of cement different from that we now employ. We have gone to quick-hardening cements, splendid for certain purposes, but generally involving sudden and large evolution of heat. Other things being equal, we would expect the finely ground cement showing more heat evolution. Chemical compositions generally found in our quick hardening portland cements would make for large heat evolutions. Perhaps not even our normal cement which we have been using for years past, is the best cement for dams or other mass concrete construction. We may come to use a cement of relatively low heat evolution—perhaps of coarse grains or high silica content, or the cement manufacturing process may play some part which will give us a low heat evolution—a cement which will gather its strength slowly, the concrete remaining in a semi-plastic condition for a longer time and therefore affording opportunity for adjustment within the mass, as it expands and contracts, so that finally there will not be left within the mass any large residual stresses. That would be a desirable type of cement for mass concrete construction. Instead of having two types of cement, the normal portland cement and quick hardening portland cement, we might have still a third for mass concrete construction—a slow-hardening portland cement of low heat generation. This committee comprises 25 members—a representative group of engineers of considerable prominence in the fields of mass concrete construction and of research. Many

of its members are in our western territory, where they are building most of the large dams, men who have been engaged in dam design and construction, some of them for a good many years, together with some of our eastern men, who are experts in the field of research. The work has been divided among four subcommittees—Laboratory program, Field program, Cement and Admixtures and Executive. The committee has had two meetings at which the cooperation of groups representing projects of large magnitude has been pledged—California's Department of Dams, the U. S. Bureau of Reclamation, the Los Angeles County Flood Control District, and others; and likewise we have the promised cooperation of the manufacturers of cement and admixtures, not only in furnishing materials and personnel for carrying out these tests under centralized administration, but also in the way of actual monetary contributions which are important, gentlemen, in tests of considerable magnitude.

It is all right in our ordinary tests to play with little briquettes, two-by-four or six-by-twelve cylinders, but when you get into mass concrete, gentlemen, it becomes a different story. There you have not only to make observations in the field under field conditions in the actual structures, but you have got to make in your laboratory, specimens of unprecedented size. In the program of tests we have laid out, some of our smallest specimens are cubic yard masses; some of our large specimens contain fifty cubic yards. One test proposed is upon cylinders 12 ft. in diameter by 12 ft. high, in each of them containing approximately 50 cu. yds of concrete. In carrying out this particular test we have not only to manufacture the cylinders but to seal them up in such a manner that they will neither give up nor absorb moisture, and keep them in a special room where the temperature will be constantly maintained outside at the same temperature as that inside the mass and automatically regulated. Inside each of these 12-ft. cylinders, devices will be imbedded for measuring the strains of the mass. Smaller cylinders will be embedded in the large and their properties determined.

We are desirous of securing the cooperation of all those who have anything to do with mass concrete construction, who have not already come forward and volunteered their services.

CONVENTION DISCUSSION

CHAIRMAN HOLLISTER—The subject of mass concrete is assuming at this time particular importance with the impending contracts for the construction of the Hoover Dam. Normally we think of 6,000 yards of concrete as being a fair sized job. One unit of the Hoover Dam itself will take 6,000 yards a day for two years, about three and a half million cubic yards of concrete in the mass of the dam itself, not including minor appurtenances running to over a million yards. The chairman of the committee on Properties of Mass Concrete is a member of the Board of Consulting Engineers on concrete on this dam. The Board consists of five men under the chairmanship of Mr. Bates, all five of them are members of this Institute.

L. G. LENHARDT—Talking about millions of yards of concrete and 6,000 yards a day for two years rather startles me. I have a few data here that I happened to jot down. On a tunnel job—12 ft. diameter and some hundred feet beneath the surface, ground temperature 55 deg.; mix used, approximately 1:2:3; water-cement ratio varied between five and a half and six and a half gallons; temperature of concrete on placement, 65 to 70 deg.; wall thickness 21 in.; temperature of the concrete, four different readings, 118 deg., 122 deg., 123 deg., 125 deg.; maximum at three days after placement. The same temperature held four days and showed slight signs of dropping off at five days. The concrete was placed at the rate of 8 to 10 yds. per hour. On another job, caisson, 8 ft. walls, outside temperature, 18 to 20 deg., concrete placed at 45 deg.; placed at the rate of 32 to 40 cu. yds. per hour with a total of 2,600 cu. yds. in the pour. Pried back face of forms at the end of 24 hours and found a temperature of 80 deg. at the face of the concrete. We had a pipe insert extending four or five inches back in the concrete and the temperature at that point was about 85 deg.

WRITTEN DISCUSSION

BY CLIFFORD BETTS

The summary of existing data on "Properties of Mass Concrete" by Committee 108 logically deals primarily with the chemical generation of heat and resulting expansion and contraction of the mass. This phase of mass concrete behavior merits intensive

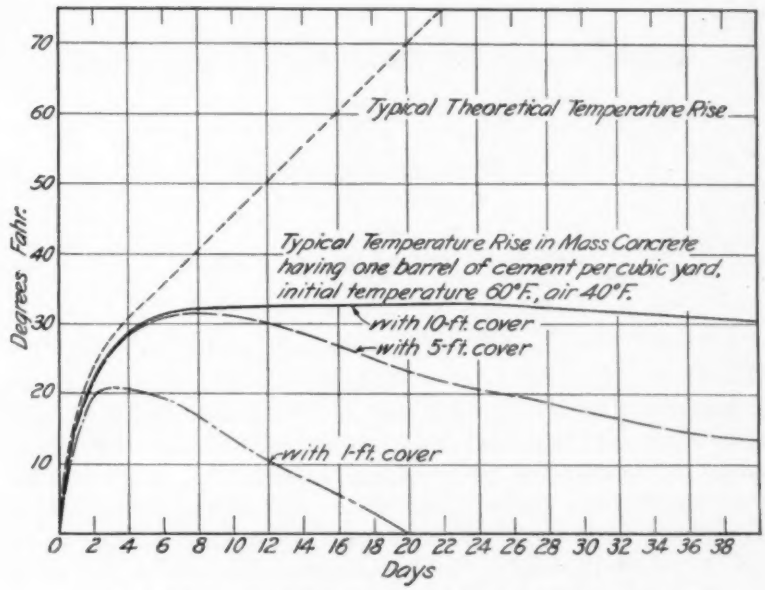
study in both the field and laboratory in order that design of large structures may not be handicapped by inadequate data. The committee has performed a distinct service in presenting a summary of research to date and a proposed program of investigations whereby future investigations may be coordinated.

Shrinkage stresses in massive concrete structures—notably dams, piers and arches—may even exceed loading stresses unless heat generation is controlled. Cracking and incipient disintegration, due to unequal contraction after expansion and to too rapid evaporation of uncombined water during early curing periods when excessive temperatures are permitted, demand that consideration be given heat control.

Rapid placing by modern methods lessens the opportunity for heat dissipation and the trend toward high early strength cements helps create a vicious circle wherein the higher temperature caused by the more rapid early chemical action in turn accelerates this action. High temperatures, caused by fine grinding, high lime or alumina content, are more evident in rich mixes and therefore enter into the design.

The heat rise in the average concrete mass will vary from 30 to 70 deg. F., within the first two weeks after placing depending upon the cement content, the thickness of cover and the ambient temperatures. Fig. 1 illustrates a typical temperature rise in mass concrete together with the theoretical rise that might be expected if no heat were lost. The cooling effect of the atmosphere upon concrete having less than ten feet of concrete cover is obvious. High initial heat in the concrete and high atmospheric temperatures raise the peak and decrease the rate of radiation. The behavior of the concrete during the cooling period following the peak temperature is influenced by the deferred hydration of the cement and, where radiation is slow, the return to normal temperature may require several years. An extensive research program disclosing the extent of such chemical action is an immediate need.

Control of heat generation involves mitigation of the causes coupled with engineering design that takes cognizance of the many influencing factors. Reducing the cement content in the mix may cut down the temperature rise as much as 40 per cent


Typical Theoretical Temperature Rise
Typical Temperature Rise in Mass Concrete having one barrel of cement per cubic yard, initial temperature 60°F., air 40°F.
with 10-ft. cover
with 5-ft. cover
with 1-ft. cover
Degrees Fahr.
Days
70
60
50
40
30
20
10
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38

EARLY TEMPERATURE RISE IN MASS CONCRETE

(although such a range is rarely possible in design). Changing cement grinding from 90 to 80 per cent fineness (per cent passing No. 200 sieve) may be made to curtail heat development 20 per cent (usually at the expense of ultimate strength). In manipulating the lime, alumina, magnesia, iron and other constituent parts of the cement to produce a slow setting concrete for mass placing, advantage can be taken of the fund of knowledge acquired in perfecting high early strength cements. The use of precast concrete blocks that can be cured under ideal moisture and temperature conditions and readily handled by cableways, offers a solution of the placing problem which rivals the common expedient of limiting the size of pours so as to facilitate radiation.

Readers are referred to the JOURNAL *for November, 1931, (Vol. 28), for further discussion which may develop. Such discussion should reach the Secretary by October 1, 1931.*

Tentative Specification for Ready-Mixed Concrete

*Report of Committee 504**

MILES N. CLAIR, AUTHOR CHAIRMAN

Committee 504 first presented at the February 1930 meeting a report[1] consisting principally of the work of the author-chairman. The specification included in that report received considerable helpful criticism and discussion. As the result of that discussion, both at the convention and at subsequent meetings of the Committee, a new specification was developed which was presented for your consideration in the November 1930 issue of the Journal. That specification was further modified by the committee at this convention, to meet the objection of some members of the committee and others interested. The specification proposed by this committee is in five sections. The first, General, logically deals with the limitation of the specification, definitions that are necessary for its understanding, and a general requirement in regard to the operation of the plant. The second deals with materials and refers generally to the usual specifications for materials. There is nothing startling nor unusual in either the first or second sections. The third section refers to concrete quality and proportioning, and this section is divided into five parts. Article A deals with concrete quality and proportioning generally, stating that they shall be in accord with the general specifications for concrete, plain and reinforced, but there is a modifying statement that the proportions may be changed at the discretion of the architect or engineer. The reason is that in the use of ready

*This report was presented by Mr. Clair at the 27th Annual Convention ,Milwaukee, February 24-26 1931, introducing the committee's recommendations for revision and tentative adoption of the specification published November, 1930; *Proceedings*, Vol. 27, p. 281. As amended and tentatively adopted by the convention, the specification follows Mr. Clair's introduction.—Editor.

[1]A. C I. Journal, February, 1930; *Proceedings*, Vol. 26, p. 467.

mixed concrete, it is frequently necessary to make changes that might not be contemplated or necessary under the general specification. Article B deals with the measurements of the concrete aggregates and the cement by weight—by weight because of the necessity for ready handling of varied proportions. Central mixing or truck mixing plant operations must deal with different proportions at almost a moment's notice. However, we were faced with the fact that some operations use bag cement, so a footnote allows the use of bag measurements if you do not split bags. You can thus safeguard more or less the accuracy of your measurements, which brings it all back practically to a weight basis. The measurement of water may be by weight or by volume; that is in accordance with the usual practice. The volume of concrete produced by the batch shall be taken as the same absolute volume of the ingredients. That statement should appear in this specification, we feel, because it is frequently a matter of controversy, and it might as well be made definite. I think there is very little difference of opinion among engineers as to how the concrete should be measured, but there seems to be a good deal of difference among contractors. The next item deals with requirements for a statement of control quantities. The engineer wants to know what goes into every load of concrete, and so he should have a statement with each load as to what does go in. The next item requires that facilities be provided at the plant to enable the architect or the engineer to check at any time the quality of the materials and the accuracy of the measurements. That is just the same way as we have it at a steel plant. They have facilities at a steel plant so you can check up on the quality of the steel. The requirements for tests are the same as in the general specification. You will recall in the original specification the requirements as to tests were more stringent, but discussion has finally resulted in the requirement that they be no more stringent than required by the general specification. Section four deals with mixing and transporting concrete. This is the item which gave rise to the most discussion, because it is here that ready-mixed concrete differs most from ordinary concrete. I think however when we consider this item of the specification, we should keep in mind that we have been doing essentially the job of the ready-mixed concrete operation for many years on

our large jobs—large dam jobs and large road jobs. If that is kept in mind, we will not be so concerned about some of the limitations. We want trucks that do not lose any of the ingredients. Second, the concrete mixer shall be of the revolving type of mixer, whether operating on the truck or at a fixed point. We do not want to go through again, at this time, the evolution of the mixer so we are requiring that it be a revolving drum type of mixer. The committee felt that the limitations on the number of revolutions and the time of mixing, the capacity, that is, the load put into the mixer, should be in accordance with the manufacturers' rating and recommendation. That of course some day may be changed. Paragraph 3 of Article A, has involved considerable discussion. As originally written in the specification published last November it read:

(3) A maximum period of .... hours may elapse between the addition of the cement to the aggregates and the placement of the concrete in the forms; but the concrete as placed shall be of the consistency and workability required by the General Specification for Plain and Reinforced Concrete.

The committee, on reconsideration, felt that the emphasis was wrong and amended the paragraph to read as follows:

(3) The concrete as placed shall be of the consistency, workability, materials and water contents as required by the General Specification for Plain and Reinforced Concrete. In no case, however, shall the time elapsing between the addition of the cement to the aggregate and the placement of the concrete in the forms be more than .... hours[5] without special permission from the architect or engineer.

A footnote to this section is likewise modified. The original footnote read as follows:

The architect or engineer must indicate the limiting period. A maximum period of one hour is recommended.

The committee has voted that this footnote also be amended, to read as follows:

The Architect or Engineer must indicate the limiting period. An elapsed time of one hour has been found satisfactory under the usual operating conditions, but the permissible time may be longer under special conditions as determined by the workability and methods of placing.

A fourth item, is usual, that concrete shall not be retempered nor partially hardened concrete be placed in the structure. The fifth item requires precautions for the protection of concrete in transport when necessary.

Section B, Under Mixing and Transporting, deals with central plant-mixed concrete, provides that the concrete shall be mixed in accordance with the general specifications before being placed in transporting vehicle. In other words, you are not to count on the agitating effect of the usual agitating or non-agitating type of vehicle as being effective. The type of truck is limited to three classes—non-agitating, which is limited by the consistency of the concrete; the re-mixing type and the agitating type. The footnote under this section originally read:

> The Architect or Engineer must indicate the limiting slump. A maximum allowable slump of two and a half inches for non-agitating type truck and six inches for remixing type truck is recommended.

We felt that this, again, did not properly place the emphasis and the committee amended it to read as follows:

> The Architect or Engineer must indicate the limiting slump. An allowable slump of two and a half inches for non-agitating type trucks and six inches for remixing type trucks has been found satisfactory under usual operating conditions, but the use of greater slumps is permissible, if it can be shown by test that the concrete can be delivered without segregation.

That, incidentally is the second point concerning which there was the most discussion. The remaining part of the specification received much better treatment. Section C, dealing with Central Plant-Proportioned Truck Mixed Concrete included a precautionary paragraph that the procedure in loading the truck mixer shall be such that the cement and aggregate are uniformly distributed throughout the truck when the loading is completed. There is a requirement that the truck be so equipped that the amount of water added and the time of agitation or the number of revolutions during the transportation can be verified.

The fifth section of the specification deals with the requirement on delivery. The first provision is that the organization supplying concrete shall have sufficient plant capacity and transportation apparatus to insure continuous delivery at the rate desired; the second recommends that the interval between loads shall not exceed thirty minutes, or in any case be so great as to allow the concrete in place to become partially hardened; and third, that the method of delivering the concrete shall be such as will facilitate placing with the minimum of re-handling and without damage to the structure or concrete.

The committee has given considerable time to this specification; and has tried to lend a receptive ear to all suggestions. One suggestion only was received from outside the committee previous to today, since the publication of the specification in November. We feel it is worthy of acceptance as a tentative specification of the Society, although we recognize that the practice in this field is moving very rapidly and that modifications may be desirable before it is moved to a standard. I move, on behalf of Committee 504, the tentative adoption of the specification published in the November 1930 JOURNAL of this Institute, as here amended. (The specification as amended and tentatively adopted follows:)

TENTATIVE SPECIFICATION FOR READY-MIXED CONCRETE

*American Concrete Institute Tentative Specification 504-31-T**

MILES N. CLAIR, AUTHOR-CHAIRMAN

Committee 504, Specifications for Ready Mixed Concrete

1. GENERAL

(A) These specifications cover the special conditions affecting the use of Ready-Mixed Concrete and supplement the requirements of the General Specifications for Plain and Reinforced Concrete for this Contract.

(B) The term "Ready-Mixed Concrete" is used in these specifications as meaning[1] Central Plant-Mixed concrete and Central Plant-Proportioned Truck-Mixed concrete.

(C) The place where the materials are proportioned is referred to in these specifications as "the plant."

(D) The operation of the plant shall be under the direct supervision of a competent engineer.

2. MATERIALS

(A) All aggregates, cement and water shall be of the quality required by the General Specifications for Plain and Reinforced Concrete. All conveyors, bins and hoppers shall be cleaned of unapproved materials before starting to manufacture concrete for this contract.

*Proposed by Committee 504, November, 1930, JOURNAL, p. 281, and now published with amendments adopted by the 27th Annual Convention, February, 1931.

[1]The Architect or Engineer must indicate which systems are allowed. It is recommended that in general both be included.

(B) No change shall be made in the materials used, during the course of this contract, except with the permission of the Architect or Engineer.[2]

3. CONCRETE QUALITY AND PROPORTIONING

(A) The concrete quality and proportions shall be in accordance with the requirements of the General Specifications for Plain and Reinforced Concrete. Proportions, however, shall be subject to change under the direction of the Architect or Engineer when necessary to produce proper workability or satisfactory strength.

(B) The measurement of the concrete aggregates and the cement[3] shall be by weight so that the proportions can be readily adjusted to assure a definite volume of concrete of the quality specified. The measurement of the water may be by weight or volume. The volume of concrete produced per batch shall be taken as the sum of the absolute volumes of the ingredients.

(C) A statement of the control quantities[4] used and the time at which the vehicle was loaded shall accompany each load of concrete. The organization supplying the ready-mixed concrete shall have available sufficient test data, certified by a competent concrete testing engineer, to enable the Architect or Engineer to determine whether the quantities used will give concrete of the desired quality and the stated quantity per batch.

(D) Facilities shall be provided at the plant to enable the Architect or Engineer to check easily at any time the quality of the materials and the accuracy of the measurements.

(E) Tests of the concrete as delivered to the forms shall be made during the progress of the work as required by the General Specifications for Plain and Reinforced Concrete.

4. MIXING AND TRANSPORTING CONCRETE

(A) *General*

(1) Transporting vehicles shall be so constructed as to insure rapid delivery without loss of ingredients.

(2) All concrete shall be mixed in a revolving drum type of mixer, whether stationary or movable. The mixing time or

[2]In the use of this specification for a particular project one of these must be stricken out throughout the text to avoid conflict.

[3]Bag measurement may be used provided the batches do not involve fractions of bags.

[4]"Control quantities" refers to the requirements of the specifications such as water-cement ratio, cement content, or proportions.

number of revolutions shall be as recommended by the manufacturer; but shall not be less than required by the General Specifications for Plain and Reinforced Concrete. The mixer shall not be loaded beyond the capacity recommended by the manufacturer.

(3) The concrete as placed shall be of the consistency, workability, materials and water contents as required by the General Specifications for Plain and Reinforced Concrete. In no case, however, shall the time elapsing between the addition of the cement to the aggregate and the placement of the concrete in the forms be more than 00 hours[5] without special permission from the Architect or Engineer.

(4) Under no circumstances shall partially hardened or retempered concrete be placed in the structure.

(5) Special precautions shall be taken to protect the materials from damage during transportation under extreme weather conditions.

(B) *Central Plant-Mixed Concrete*

(1) The Concrete shall be properly mixed in accordance with the requirements of the General Specifications for Plain and Reinforced Concrete before being loaded into the transporting vehicle.

(2) Non-agitating type transporting vehicles shall not be used to transport Central Plant-Mixed concrete when the consistency of the concrete is wetter than a —-inch slump.[6]

(3) Remixing type transporting vehicles[7] shall not be used to transport Central Plant-Mixed concrete when the consistency of the concrete is wetter than a —-inch slump.[6]

(4) Agitating type transporting vehicles may be used without restriction as to consistency.

(C) *Central Plant-Proportioned Truck-Mixed Concrete*

(1) The procedure in loading the truck mixer[8] shall be such

[5]The Architect or Engineer must indicate the limiting period. An interval of one hour has been found satisfactory under the usual operating conditions, but the permissible time may be longer under special conditions as determined by the workability and methods of placing.

[6]The Architect or Engineer must indicate the limiting slump. An allowable slump of two and a half inches for non-agitating type trucks and six inches for re-mixing type trucks has been found satisfactory under usual operating conditions, but the use of greater slumps is permissible, if it can be shown by tests that the concrete can be delivered without segregation.

[7]Re-mixing vehicles are those provided with special means of remixing or agitating the concrete to some degree during discharge but not during transportation.

[8]It is suggested that the cement and aggregates be fed simultaneously into the end loading type of truck mixer. For the top loading type of mixer this method of charging is not so essential; but is also recommended.

that the cement and aggregates are uniformly distributed throughout the batch when the loading is completed.

(2) Where the concrete is mixed during transportation of the batch to the job, means shall be provided so that the mixing time and the quantity of water added can be readily verified by the Architect or Engineer.

5. DELIVERY

(A) The organization supplying concrete shall have sufficient plant capacity and transporting apparatus to insure continuous delivery at the rate required.

(B) The interval between loads shall not exceed — minutes,[9] or in any case be so great as to allow the concrete in place to become partially hardened.

(C) The methods of delivering the concrete shall be such as will facilitate placing with the minimum of re-handling and without damage to the structure or concrete.

[9]The Architect or Engineer must indicate the interval allowed. A maximum of thirty minutes is recommended.

Tentative Construction Specification for Concrete Work on Ordinary Buildings (502-31-T)

*Report of Committee 502**

ARTHUR R. LORD, AUTHOR-CHAIRMAN

The report of Committee 502 was published in the Journal for November, 1929.[1] Discussions (published in March, 1930,[2]) prompted the Committee to make several revisions designed to cover all valid objections. As thus amended, by the Committee, the specification was tentatively adopted by the Institute by vote of the Convention at New Orleans a year ago.

In the early discussion the rather severe treatment accorded admixtures in this proposed standard went unchallenged. As time went on, however, I understand that this report began to cause the "Admixture Boys" (I borrow this convenient term from the discussion of one of them) some embarrassment. In considering their distress it is but fair to remember that the subject of admixtures has caused the Advisory Committee embarrassment also. Our long projected committee to report on admixtures has been the most difficult committee we have had to deal with in recent years. Only after long search and several tumbles have we found a man to head this committee who possessed the necessary freedom from prejudice, reputation for fairness and scientific accuracy, together with sufficient backbone to deal firmly with such experienced and persuasive gentlemen as the "Admixture Boys."

That was the situation when the Program Committee put this committee report on for discussion, with the committee proposing to ask that the tentative specification be sent to letter ballot for

*This report was presented by Mr. Lord at the 27th Annual Convention, Milwaukee, February 24-26, 1931.

[1]A. C. I. *Proceedings*, Vol. 26, p. 1.

[2]A. C. I. *Proceedings*, Vol. 26, p. 580.

adoption as a full standard. Since its tentative adoption three discussions brought up for the first time, the subject of the highly obnoxious Article 10. These discussions were published in the JOURNAL of September, 1930.[3] Fortified by an excellent dinner, stimulated by the hearty fellowship of last evening, the "Admixture Boys" decided to confer rather than to dance. Having reached without difficulty the unanimous conclusion that Article 10 was hostile and that something should be done about it at the eleventh hour, I was sent for. My personal safety was assured by the presence of Mr. Goldbeck as arbitrator, and I am pleased to recommend him for that service should any other group stand in a similar need.

I have never before seen so many admixture representatives peaceably assembled. If Article 10 serves no more useful purpose than to bring the representatives of all admixture manufacturers to a realization that their interests are mutual rather than opposing, that the very information that Committee 502 demands for the safe guidance of the users of admixtures is the thing most helpful to the admixture business, its brief existence will have been worth while. The meeting gave a free and full opportunity for frank discussion of the attitude of this committee—in which it is no less unanimous than the admixture representatives—towards this subject. After a few hours of friendly and hearty debate we all went into a huddle with the referee and as a result I am privileged to submit the "Goldbeck formula" for the consideration of the convention at this time.

The Goldbeck solution strikes out the first two paragraphs of the present Article 10 and substitutes one new paragraph.

Article 10 in the original publication of the proposed specification follows:

10. ADMIXTURES AND SPECIAL CEMENTS.

Nothing shall be added to the essential ingredients of concrete (portland cement, fine and coarse aggregate, and water) without the approval of the Architect or Engineer in writing and then only such materials shall be added as have been thoroughly tested by reputable independent investigators so as to demonstrate their effect on the strength, elastic properties, permeability and permanence of concrete produced from materials such as are being used on this work.

[3] A. C. I. *Proceedings*, Vol. 27, p. 99.

No special cement shall be used in place of standard portland cement except upon the same basis of adequate test and known effect upon all vital properties of the resulting concrete.

Whenever such admixtures or special cements are approved for use on this work in this manner they shall be used in accordance with the manufacturer's instructions and in conformity with their use in the tests on which their acceptance is based.

The paragraph which it is now proposed to substitute for the first two quoted above, follows:

Materials proposed for use in concrete in addition to the essential ingredients (portland cement, fine and coarse aggregate and water), or special cements proposed for use in place of standard portland cement, shall be permitted only with the approval of the Architect or Engineer in writing, on the basis of acceptable tests to demonstrate thoroughly the effect of such materials on the strength, elastic properties, permeability and permanence of the concrete.

The final paragraph of Article 10 is to stand.

The committee also wishes to make another change in this specification, designed to permit the use of cement in bulk as follows: At the end of the first sentence of the second paragraph of Article 5 add a new clause reading:

. . . except that cement may be shipped in bulk direct from manufacturers storage to this work, or to the central mixing plant where the concrete for this work is proportioned.

With these two changes I move you, Mr. Chairman, that tentative specification 502-30-T be approved as amended and be continued as a tentative specification of this Institute—502-31-T. While no arrangement was made to this effect last night—this morning, rather—I trust that some admixture representative will be gracious enough to second my motion.

He was, and the motion was carried without dissent.

Tentative Construction Specification for Concrete Work on the Small Job (506-31-T)

Report of Committee 506

ARTHUR R. LORD, AUTHOR-CHAIRMAN

Arthur R. Lord, author-chairman Committee 506, proposed, at the 27th Annual Convention, February 24-26, 1931, amendments to Articles 4 and 10 of Proposed Construction Specification for Concrete Work on the Small Job—first published as a report of the Committee in this Journal, September, 1930,[1] and discussed January, 1931.[2]

Article 4 in its original form and as amended is shown in the following—the words underlined to be deleted and italic indicating new wording:

4. Concrete materials

Portland cement shall be used for all concrete work. This cement shall be certified by the dealer to comply with all requirements of the standard specifications of the American Society for Testing Materials. (Serial designation: C9-26, or latest standard of this Society.)

Aggregate for this work shall be certified by the dealer (See Note 1 opposite)* to comply with the following specifications:

Fine aggregate for this work shall consist of well graded natural or artificial sand, or other approved inert materials with similar characteristics, taken from sources that have furnished satisfactory materials for previous concrete work for several years, or if from a new source shall be thoroughly tested for soundness and permanence. It shall comply with the provisions of the Tentative Purchase Specifications for Concrete Aggregates, E5-A-26T, *E5-A-29T*, (or latest standard of the Institute) of the American Concrete Institute. In applying these provisions the sieve analysis of dried aggregate shall show as follows:

Passing No. 4 sieve—not less than 85 per cent.

Passing No. 50 sieve—between 5 and 30 per cent. (Note 2 opposite.)

*References (see note opposite) are to the original printing of the specification where the "whys" of the provisions are discussed—Editor.

[1]A. C. I. *Proceedings*, Vol. 27, p. 65.

[2]A. C. I. *Proceedings*, Vol. 27, p. 525.

Passing No. 100 sieve—not more than 5 per cent.

Fineness Modulus—not less than 2.50

and the weight of clay and silt removed by decantation shall not exceed 3 per cent.

Coarse aggregate for this work shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or other approved inert materials of similar characteristics, taken from sources that have furnished satisfactory materials for previous concrete work for several years or if from a new source shall be thoroughly tested for soundness and permanence. It shall comply with the provisions of the Tentative Purchase Specifications for Concrete Aggregates, E5-A-26-T *E5-A-29-T* (or latest standard of the Institute) of the American Concrete Institute. *The maximum size of the coarse aggregate shall be one inch unless the use of a larger maximum size is directed by the Architect or Engineer.* In applying these provisions the sieve analysis of dried aggregate shall show as follows:

Passing 1-inch sieve—not less than 95 per cent.

Passing No. 4 sieve—not more than 10 per cent.

Passing No. 8 sieve—not more than 5 per cent.

Fineness Modulus—between 6.30 and 7.50.

The weight of slag shall not be less than 65 lb. per cu. ft. The weight of soft, friable, thin, elongated or laminated pieces shall not exceed 3 per cent.

Aggregates shall be so stored and handled at all times as to remain separate from each other and free of all foreign material until placed in the mixer. (See Note 5.) Drainage shall be provided where necessary to avoid accumulation of water in aggregates.

Water shall be taken from the usual drinking supply and shall be paid for by this Contractor.

The same materials shall be used throughout the work, including the same brand of Portland Cement from the same mill, the same sand and gravel or crushed rock from the same source and from the same bin at the screening plant. (See Note 3.) This Contractor shall be fully responsible for the correct certification of all materials by the material dealer, as provided above. In case of doubt this Contractor shall pay for the necessary tests to be made under the direction of the Architect or Engineer.

To Article 10: "Measurement of the Batch" a new paragraph is added as follows:

When the concrete mix is determined by means of preliminary tests made by an approved laboratory and using the same materials as are to be used in the work, the water-cement ratio to be used in the work shall be taken as that giving a strength under standard laboratory conditions, at the age at which the concrete is to be put into service, not less than fifteen per cent greater than the ultimate strength required of the concrete in the work.

Both these amendments were accepted by the Convention and as thus amended the specification was tentatively adopted.

Tentative Specification for Supplying, Fabricating and Setting Reinforcing Steel on Ordinary Buildings (503-31-T)

Report of Committee 503

W. F. ZABRISKIE, AUTHOR-CHAIRMAN

The report of this committee published in this Journal, February, 1930;[1] formally presented at the 26th Annual Convention, New Orleans, February, 1930, and discussion published in this Journal, June, 1930,[2] was presented to the 27th Annual Convention, Milwaukee, February, 1931, for tentative adoption of the Proposed "Specification for Supplying, Fabricating and Setting Reinforcing Steel on Ordinary Buildings" with an appendix: "A Steel Setters Primer," motion by Mr. Zabriskie was seconded and adopted. The document now takes the serial designation as a tentative specification "503-31-T."

[1] A. C. I. *Proceedings*, Vol. 26, p. 444.
[2] A. C. I. *Proceedings*, Vol. 26, p. 910.

ABSTRACTS

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of the current literature of cement and concrete

PREPARED UNDER THE DIRECTION OF THE
AMERICAN CONCRETE INSTITUTE
COMMITTEE ON ABSTRACTS

J. C. WITT, Chairman, (*Materials*)
H. F. GONNERMAN (*Properties of Concrete*)
F. E. RICHART (*Engineering Design*)
REXFORD NEWCOMB (*Architectural Design*)
THEODORE CRANE (*Field Construction*)
W. D. M. ALLAN (*Shop Manufacture*)

EDITED BY DWIGHT F. JENNINGS

ABSTRACTORS

JOHN E. ADAMS
F. O. ANDEREGG
ROBERT W. ABBETT
ODD ALBERT
S. O. ASPLUND
C. BACHMANN
P. H. BATES
A. E. BEITLICH
A. A. BRIELMAIER
V. E. BUTLER
MILES N. CLAIR
C. G. CLAIR
IRA L. COLLIER
M. A. CORBIN
R. J. DIETRICH
E. L. ERIKSEN
H. FRAUENFELDER
W. I. FREEL
P. J. FREEMAN
H. J. GILKEY
A. T. GOLDBECK
J. E. GRAY
E. S. HANSON
S. C. HOLLISTER
A. J. HOSKIN
F. H. JACKSON
V. P. JENSEN
D. E. LARSON
H. WALTER LEAVITT
L. G. LENHARDT
A. E. LINDAU
ARTHUR R. LORD
H. J. LOVE
P. MCKIM
JOSEPH MARIN
N. D. MITCHELL
R. B. B. MOORMAN
GLENN MURPHY
REXFORD NEWCOMB
J. C. PEARSON
C. E. PROUDLEY
F. E. RICHART
N. H. ROY
J. H. SHANK
EDMUND SHAW
A. SIZE
T. U. TAYLOR
T. THORVALDSON
G. E. TROXELL
H. S. VAN SCOYOC
STANTON WALKER
G. M. WILLIAMS
C. R. YOUNG
ROY N. YOUNG

MATERIALS

AGGREGATES

Concrete from Slag. J. BENTKOWSKY. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—The report deals with a series of tests carried out by the Institute of Metals in Leningrad with a view to studying possibility of using a given slag for manufacture of concrete, and determining the mix from these tests in relation to workability and strength.—EDITORS N. I. A. T. M.

Influence of split on strength of cast concrete. LUZ DAVID. *Zement* (Germany), Jan. 8, 1931, V. 20, No. 2, p. 32-7.—Field tests were made to study improving effect of additions of split to concrete on its compressive strength. One high-grade quartzite split and a low-grade quartz porphyry split were used in 1:1:5 and 1:2:4 (cement-split-sand) mixtures. It was found that compressive strength is considerably increased by even small additions (1/5 of sand) of split. This increase is greater when high early strength cement is used. In this latter case, low-grade split seems to give greatest increases in strength. Question whether such additions are economic in practice or not is discussed and ideal conditions described. Price of split and facilities at site of construction are chief governing factors.—A. E. BEITLICH

Plant design and practices—Part 1. G. W. MAISAK. *Rock Products*, Feb. 28, 1931, V. 34, No. 5, p. 71.—The first problem considered is that of a feed hopper to a primary crusher, in this case a jaw crusher. A common form uses old rails for lining. These should never be set at an angle greater than 40 deg. to minimize damage from surges of rock. This type of hopper is affected by weather conditions and the amount of dirt coming from quarry. Stone-on-stone type of feed box is favored, as once built it needs no further attention. In the larger plants it should be made of fabricated steel.—EDMUND SHAW

Barges bring aggregate to ready-mixed concrete plant at Tacoma. CHAS. F. A. MANN. *Pit and Quarry*, March 11, 1931, V. 21, No. 12, p. 56-58.—At new concrete plant of George Scofield Co., which produces Tru-Mix concrete, aggregates are received on barges, chiefly from pits belonging to an interlocking company. Barges are unloaded by hammerhead crane built in company's shops and which rests on a steel framework above piling. The 65-ft. boom carries a 2½-cu. yd. clamshell bucket, and handles 65 cu. yd. per hour into a 10-cu. yd. steel hopper. Material drops to belt conveyor which delivers to conveyor on upward slope of 15 deg. to the storage house. Material can be deposited on bunker-storage belt or carried to bunkers above mixing platform. Bunker-storage belt delivers to the bins. Beneath the storage a conveyor will reclaim the material and beneath the bunkers of the mixing plant the steel chutes have cut-off gates to the scale pan above the mixer. Pan has steel chute to 2-cu. yd. mixer beneath. Cement now measured in a small steel dump-cart will be handled same way as aggregates. A mixometer provides an accurate check on concrete inside the mixer. Concrete is delivered by trucks.—A. J. HOSKIN

Aerial photography in the aggregates industry. HOWARD MAXWELL. *Rock Products*, Feb. 28, 1931, V. 34, No. 5, p. 41.—It is often imperative to have maps of aggregate operations, construction projects and sites for either of these. Aerial photographs make best maps, being absolutely accurate and showing details that could not be shown in maps without excessive cost. Now even amateurs who thoroughly understand photography may make aerial photographs that will serve ordinary purposes. Comparatively small areas can be covered with one or two exposures. An exposure made at 7,200 ft. with

a camera of ordinary size will give an accurate map of approximately 200 acres at a scale of 1 in. to 600 ft. This can be enlarged to any scale up to 1 in. to 200 ft. Wide angle lenses are not recommended as they are liable to produce distortion and are usually slower than other lenses.—EDMUND SHAW

Fifth annual report of the engineering and research division. STANTON WALKER. *Nat. Sand Gravel Bul.*, Feb., 1931, V. 12, No. 2, p. 29-37.—Brief summary of work under way in laboratory of National Sand and Gravel Association includes: (1) Effect of characteristics other than grading on concrete-making properties of concrete aggregates—includes studies of mineral composition, surface texture, strength, shape and miscellaneous physical properties of coarse aggregate particles. (2) Effect of size and grading of aggregate on quality of concrete—deals principally with coarse aggregates, although preliminary studies of fine aggregates have been made. (3) Method of proportioning concrete—the development of a logical and scientific basis of proportioning concrete is essential to studies of aggregates for concrete, and is particularly pertinent to the investigations mentioned above. (4) Tests of sand—studies to date have been of a preliminary and exploratory nature, but they indicate the need for a comprehensive investigation. (5) Characteristics of gravel ballast—studies of physical properties and service records of gravel ballast and preliminary work in a study of methods for testing stability of ballast of different types and gradings. The principal efforts of the laboratory for the coming year will be directed to the study of the following problems: Effect of coarse aggregate characteristics other than grading on strength of concrete; methods of tests for durability of aggregates and concrete; correlation of tests of sands with their concrete-making properties; and studies of size and grading of aggregates with particular reference to methods for proportioning fine and coarse sizes for concrete.—P. MCKIM

Produces aggregates and central-mixed concrete for Philadelphia area. *Pit and Quarry*, Feb. 25, 1931, V. 21, No. 11, p. 27-31.—Aggregates used by Liberty Corp., are dredged from the Delaware River and transported in barges to dock at plant. Material averages 60 per cent sand, 40 per cent gravel. Dredge is of steel construction and of the bucket-ladder type. Products of four grades are chuted to barges. At the unloading dock materials are handled by a gasoline crawler crane and electric locomotive crane with clamshell buckets. First crane dumps oversize stone to hopper of crushing-screening department, and electric crane unloads sand and gravel to truck-loading bins or distributing-plant hopper. All bins have steam coils to heat aggregates in freezing weather. The dry-batching unit has a 2-compartment steel bin of 200 ton capacity. Aggregates are weighed in a 2-compartment 6-ton batcher with automatic attachment, and are discharged directly into trucks. Mixer unit has a 4-compartment steel bin of 300 ton capacity for aggregates in three compartments, and four carloads of cement in the fourth compartment. Bulk cement is power-scooped from cars and elevated to storage bin. Cement is withdrawn from its bin by a screw conveyor to the cement weighing batcher. Batches are weighed into a 3,000-lb. weigh hopper and then discharged to 3-cu. yd. mixer. Deliveries of concrete are made by a fleet of trucks with 4-cu. yd. agitator bodies.—A. J. HOSKIN

Tests of plain and reinforced Haydite concrete. F. E. RICHART AND V. P. JENSEN. *Proc. A. S. T. M.*, 1930, Part 2, V. 30, p. 674-693.—This paper furnishes data on structural properties of poured Haydite concrete. The mixtures include concretes made with fine and coarse Haydite aggregates, natural sand and coarse Haydite, and for comparison, sand and gravel or broken limestone. An initial series of tests was made on beams and cylinders of machine-mixed concrete to secure information on mixes suitable for ordinary reinforced-concrete construction, with particular attention to securing workability, surface finish, and freedom from segregation. The investigation in-

cluded tests on 75 beams, 27 pull-out specimens, and nearly one thousand 6 by 12-in. cylinders. With the consistencies used, no difference was noted in work required to place concrete, or in appearance of the molded surfaces of beams made with gravel, limestone, or Haydite. The gradation and texture of Haydite aggregates required a somewhat greater water-cement ratio than gravel aggregate in similar mixes, and consequently gave a lower strength concrete. Absorption allowance is not fixed, but depends on initial moisture content of aggregate as used. For equal water-cement ratios, strengths of concretes made with sand and gravel, sand and coarse Haydite, and fine and coarse Haydite are very nearly equal. There was no indication that strength was limited by strength of aggregate. The modulus of elasticity of Haydite concrete is markedly lower than that of ordinary concrete of like proportions. The density ranged from 93 to 126 lb. per cu. ft. depending upon the amount of sand present, variation in mixture, and moisture control of aggregate. Up to 6 mo. at least, increase in strength with moist curing is comparable with gravel concrete. Bond and diagonal tension resistance are about the same proportion of compressive strength for Haydite concrete as for gravel concrete.—GLENN MURPHY

CEMENT

About the use of pumice as a raw material for cement manufacture. M. STILLER. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 51-4.—Possibilities for use of pumice as a raw material (instead of clay) are discussed and investigated by synthetic burns with a number of different kinds of pumice and trass. Clinkers were burned in experimental shaft kiln. Analysis of raw and finished products are given. Clinkers show flash sets and need additions of gypsum from 4 to 6 per cent to obtain normal setting properties. Alkali content is high, which fact lowers burning temperature considerably. In a rotary kiln a great part of alkali can be volatilized. Economic importance of these methods is illustrated.—A. E. BEITLICH

Quicker tests of cement and concrete. H. KREUGER. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Several preliminary tests have been made in order to investigate the possibility of deciding quickly (in 1 or 2 days instead of 28 days) if a cement is fit for delivery. Tests have proved that there probably may be a fairly good concordance between the normal crushing strength of cubes by 28 days combined air-and-water curing and by steam-hardening in a few hours. Method may be of some use also by quicker testing of concrete. It, however, is not yet satisfactorily developed, but seems worthy of some attention.—EDITORS N. I. A. T. M.

Portland cement plant in Sonora, Mex., to start production in March. *Pit and Quarry*, Feb. 25, 1931, V. 21, No. 11, p. 20-22.—Wet-process plant of Cemento Portland Nacional, S. A., at Hermosillo, Sonora, is nearly completed with daily capacity of 500 bbl. Abundance of fine limestone and clay occur close to plant will be hauled by motor trucks. Stone will pass through gyratory crushers and will then be conveyed to the mill-feed bin or stored. Raw grinding will be 2-compartment mill, the slurry being pumped to four tanks having pneumatic agitation. Pumps will transfer slurry from the tanks to the kiln feeder. Clinker will be taken by drag conveyor for storage or delivery to finish compartment mill. Gypsum is fed by the same conveyor. Cement will be handled to storage silos by a screw conveyor and a bucket elevator. From the silos, cement will be withdrawn to elevator to packer bin for 2-tube packer.—A. J. HOSKIN

The testing of cements by means of earth-moist and plastic mortars. J. P. LOEVENTHAL. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Former comparative investigations carried out by Danish state testing

house are noted, in which Swiss prism method and common hammer method were used; in continuation, a series of tests dealing with mortars of portland cement, aluminous cement and a Danish pozzuolana cement (Moler cement) is discussed. Test-pieces were made in compact moulds and were of consistencies ranging from earth-moist to fluid. They were tested at 7 and 28 days. It was shown that at both dates strength curves of portland and Moler cements ran fairly similarly, although there was no proportionality. In contrast with this, mortars of aluminous cement, of low water content, showed an increase in strength between 7 and 28 days, while mortars of high water content a fall in strength. The various methods of testing are discussed.—EDITORS N. I. A. T. M.

Chemical action of gypsum and other retarders on portland cement clinker. L. FORSEN. *Zement* (Germany), Nov. 27, Dec. 4, 11, 1930, V. 19, No. 48-50, p. 1130-4, 1155-60, 1184.—Reactions which take place when cement and water are mixed and setting problem of portland cement were studied. Especially effect of different retarders was investigated and explained from standpoint of chemistry of complex compounds. It was found, that chiefly calcium aluminates react with retarding agents. Clinker and cement were agitated with water and amount of alumina, which went into solution was determined by chemical analysis. Isolation of several compounds was possible and these were studied under microscope. Retarding effect of following soluble calcium salts was studied: $CaSO_4+\frac{1}{2}H_2O$, $CaSO_2+2H_2O$, $CaCl_2$, $CaBr_2$, CaI_2, $Ca(ClO_3)_2$, $Ca(IO_3)_2$, $Ca(NO_3)_2$ and $Ca(NO_2)_2$. A number of structural formulas for products which are formed in such reactions are derived. Behavior of mixtures of portland cement and high alumina cements are discussed.—A. E. BEITLICH

The strengths of Swiss portland cement—Die festigkeiten der schweizerischen portlandzemente. M. ROS. Eidg. Materialprüfungsanstalt, Zurich. *Wochenschriift des Niedersteörreischen Gewerbevereines* (Switzerland), April 17, 1930, 4 p.—Great advances have been made in the improvement of the strength qualities of cement in Switzerland during the last 50 years. Average tensile and compressive strength on moist rammed 1:3 test mortars increased approximately 4 fold between 1881-3 and 1925. Curves show these increases in strength. High early strength cements are included for recent years. Graphs also show tensile and compressive strengths as well as flexure (bending) at 3, 7 and 28 days. Comparison of compressive and tensile strengths for moist rammed and plastic 1:3 test mortars show that the compressive strengths of the plastic are about 60 per cent of those of the moist rammed at the same ages, whereas, the tensile strengths of the plastic mortars are about 30 per cent greater than those of the moist rammed.—H. G. FISK

Preparation and characterization of dicalcium silicate, tricalcium silicate and tricalcium aluminate. I. WEYER. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 48-51.—In connection with work on reactions between kaolin and lime, it was necessary to prepare chemically pure the following compounds: dicalcium silicate, tricalcium silicate and tricalcium aluminate. (1) Dicalcium silicate was prepared from calcium carbonate and silica in a 2:1 mixture by alternating heating, at 2552° F., cooling and mixing. The two modifications, β- and δ- form were separated by fractionated centrifuging in a methylen iodide-acetylen tetrabromide mixture. Optical constants were investigated by microscope and X-ray analysis. Results obtained are in close agreement with findings of American investigators. (2) Tricalcium silicate was prepared at 3452° F. and was obtained in very pure form after several heat treatments. Free lime was present only in small traces. Optical properties are given which prove again unobjectionable existence of this compound. X-ray determinations were made. (3) In a similar manner tricalcium-aluminate was obtained in well crystallized form. Three tables show lines obtained by

X-ray analysis with relative intensity, and they are compared with results by Brownmiller and Harrington. Sixteen references are given.—A. E. BEITLICH

Small-piece testing for strength of cement mortars—Part 3. SHOICHIRO NAGAI. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), Feb., 1930, V. 33, Supplemental Binding, No. 2, p. 46-7B.—Formula is given for relation between compressive strength of 1:3 cement-sand mortar tested by ordinary test method and compressive strength tested with small cylinder method. Effect of water-cement ratio on compressive strength measured by small-piece testing method is illustrated and discussed for several different cements. Constants of strength formula (derived in previous paper) were calculated and difference pointed out between portland cement, blast furnace slag cement, soliditit, neo-soliditit and high alumina cements. Subject is still under investigation. (cf. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), March, 1930, V. 33, Supplemental Binding No. 3, p. 290-5B; JOURNAL A. C. I., Dec., 1930, V. 2, No. 4, *Abstracts* Sect., p. 99.)—A. E. BEITLICH

Zeolites and cements. HENRI LAFUMA. *Revue materiaux constr. trav. publics*, Jan., Feb., 1931, No. 256, 257, p. 1-5, 45-49.—The first part of this paper presents a study of the zeolites and the hydrated salts of cement. Hydrated aluminates and corresponding double salts occur uniformly as hexagonal crystals, negatively monoaxial. Greatly marked symmetry of these crystals—for such complex substances—and their resemblance to similarly hexagonal crystals of hydrated lime, lead to conclusion that their crystalline structure is determined by only a part of the molecules, namely molecules of hydrated lime (a common constituent). In this way are derived all properties so closely resembling salts of zeolites. This resemblance in structure also results in possibility of numerous solid solutions between all these bodies and furnishes an explanation for widely divergent results obtained by different investigators. If similar properties were to be discovered for silicates of hydrated lime, these crystalline structures would assume an important role in determining hydraulic properties. It would be interesting to establish hydraulicity as a specific property of hydrated salts possessing certain structures. Second part of paper reviews above statement, though limited by scant available knowledge concerning silicates of hydrated lime. A new concept, "the adherence structure," arises to supply a novel interpretation of "hydraulicity" phenomenon. Reference is made to original tests and to researches in different countries.—M. A. CORBIN

Studies on calcium ferrites and iron cements—Part 1. SHOICHIRO NAGAI AND KATSUHIKO ASAOKA. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), April, 1930, V. 33, Supplemental Binding, No. 4, p. 130-3B.—In systematic study of combination between ferric oxide and lime in high lime mixtures such as $3CaO:1Fe_2O_3$, $5CaO:1Fe_2O_3$, etc., determined ferrite with highest possible lime content was determined as $2CaO.Fe_2O_4$ and not $3CaO.Fe_2O_3$. Mixture of $3CaO:1Fe_2O_3$ was heated at various temperatures above 1652° F. and properties of final products, especially their solubility in 0.5 N-HCl, were studied. Dicalcium ferrite $2CaO.Fe_2O_3$ dissolves easily while $CaO.Fe_2O_3$ remains insoluble. Similar results were obtained with mixtures of $5CaO:1Fe_2O_3$ and $2CaO:1Fe_2O_3$. Dicalcium ferrite is easily prepared by heating mixture above 2192° F. It was not possible to prepare $3CaO.Fe_2O_3$ even at temperatures between 2550° and 2640° F. Results of heating tests of mixtures: $3CaO:Fe_2O_3$, $5CaO:Fe_2O_3$ and $2CaO:Fe_2O_3$ are given in tables. (cf. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), May, June, July, Aug., 1930, V. 33, Supplemental Binding, No. 5-8, p. 161-4B, 190-2B, 256-9B, 312-5B; JOURNAL A. C. I., Dec., 1930, March, 1931, V. 2, No. 4-7, *Abstracts* Sect., p. 96, 190.)—A. E. BEITLICH

A study of fourteen brands of standard portland cements and four early-strength cements. C. H. SCHOLER AND L. H. KOENITZER. *Proc.*

A. S. T. M., 1930, Part 2, V. 30, p. 581-593.—Only two or three of brands of cement reported in this paper were included in the 1928 report of Committee C-1 of the A. S. T. M. Data is presented on the relationship between chemical ingredients of each brand of cement, time of set, normal consistency, fineness and specific gravity of the cements, slump and flow tests, density of mix, tensile and compressive strengths of mortars, and flexural and compressive strengths of concretes. The general impression from the data is that of rather unusual uniformity. The principal variation in the different brands was their sensitivity to a small change in water content in the mixes at basic water content and above.—GLENN MURPHY

Canada Cement adapts plant at Hull to wet process of manufacture. W. E. TRAUFFER. *Pit and Quarry*, Jan. 14, 1931, V. 21, No. 8, p. 27-32, 26 ill.—Two years ago Canada Cement Co., began conversion of its No. 3 plant at Hull, Que., from dry to wet process. Stone from quarry is loaded by electric shovel into side-dump cars, hauled to plant by gasoline locomotive, hauled two carloads at a time, up an incline and dumped into jaw crusher. From crusher, stone is fed to hammermill discharging onto belt conveyor and is carried to the 2,200-ton storage. Clay is loaded by a gasoline-electric shovel, hauled by gasoline locomotive and dumped through a grizzly into wash mill. The slip is pumped about 1,800 ft. to basin with traveling agitator. Stone passes to feed bins above two raw-grinding mills, each mill having a 600-h. p. motor. Slurry, with 40 per cent water content, goes to correction basins with mechanical and pneumatic agitators, discharging to mixing basin with a quadruple mechanical and compressed-air agitators, then into storage basin with traveling agitator. Slurry is pumped thence to ferris-wheel feeder of 365-ft. kiln, 11 ft. 3 in. and 10 ft. in diam. A 10 section, single-row revolving cooler surrounds discharge end of kiln. Draft is furnished by two fans. Cooler discharges to two conveyors, to open storage or to the finish-mills tanks. Gypsum is fed to same conveyor. Preliminary finish grinding is with eight ball-mills, final grinding with seven 5-ft. by 22-ft. mills. Cement is screw-conveyed and elevated to 250,000-bbl. stockhouses. Other conveyors and elevators take storage cement to packhouse to packers.—A. J. HOSKIN

Some properties of high alumina-cements from six countries. P. H. BATES. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—High alumina cements (ciment fondu) manufactured in six different countries have been examined for their properties by chemical, petrographic and physical methods. The physical characteristics were determined by strengths in the form of 1:3 standard Ottawa sand tensile briquettes and 2-in. compression cubes. Concrete was also tested in the form of 6 by 12-in. cylinders made from a 1:2:4 mix of gravel. The chemical analyses showed the cements were rather widely different from one another. Petrographic examination showed that alumina was largely present either as $CaO\ Al_2O_3$ or as the unstable form of $5\ CaO\ .\ 3\ Al_2O_3$. The wide variation in composition and the difference in constitution did not result in as great a difference in physical properties as would be expected. The effect of heat generated during setting of cement, and effect of amount of mixing water used was also studied. Increased temperatures during setting resulted in decreased strength. Increased amounts of mixing water resulted also in marked decrease in strength.—EDITORS N. I. A. T. M.

Hydraulic additions and trass-portland cement. S. I. DRUJININ. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Volcanic tuff from the Crimea and diatomaceous earth from tested sources, when ground to fineness of portland cement and added to portland cement clinker, give pozzuolana-portland cement which, when used in hydraulic structures, is more resistant to sea water and acid water than is portland cement mortar. Its mechanical strength after two months hardening in water is equal to that of ordinary portland cement mortar without hydraulic addition, using the same

quantity of sand. The best methods for rapidly determining degree of activity of hydraulic addition, are to estimate the amount of lime it absorbs, and to compare strength of mortars, with and without such addition, under conditions afforded by accelerated hardening of the test-pieces at 80 deg. C. The best method for determining optimum addition of hydraulic material is the above-mentioned accelerated or thermal method. Pozzuolana-portland cement produces a more voluminous paste than ordinary portland for same quantity of sand.—EDITORS N. I. A. T. M.

Clinker shipped 200 miles by water is ground at distributing plant. W. E. TRAUFFER. *Pit and Quarry*, Feb. 11, 1931, V. 21, No. 10, p. 57-61.—Storing and packing plant of Great Lakes Portland Cement Co., Cleveland, O., operates on clinker transported from the Buffalo, N. Y., plant of same company in self-unloading boat. At Buffalo plant clinker coolers discharge to conveyors that distribute clinker to concrete silos which feed to belt conveyor discharging clinker through a telescopic spout on a boom into boat having cargo capacity of 37,000 bbl. Five hours are required for loading, 16 hours for the voyage to Cleveland, and 8 hours for unloading. Same boat also transports cement rock from northern Michigan to the company's Buffalo plant. When unloading, boat's boom conveyor discharges the clinker into the boot of a bucket elevator from which clinker is discharged through split chute to concrete storage silos. Clinker is withdrawn through gates under silos and conveyed to mill building. Gypsum is received in hopper-bottom cars. Clinker and gypsum are ground by 30-ft. 3-compartment mill. Screw conveyors take finished product to cement-storage silos. Cement from storage is conveyed and elevated to vibrating screens, to hoppers, to automatic packers for shipments.—A. J. HOSKIN

The rate of hydration of cement clinker—Part 2 and 3. F. O. ANDEREGG AND D. S. HUBBELL. *Proc. A. S. T. M.*, 1930, Part 2, V. 30, p. 572-578.—Part 2—Direct comparison of hydration rates of partially hydrated commercial portland cements ground under oil checked the rates of material ground in air within 1 per cent. At 9 months the effect of calcium sulfate or calcium chloride on rate of hydration was negligible. Apparent depth of hydration of standard portland cement was 3.54 microns at 1 month, 5.12 microns at 3 months, 7.2 microns at 9 months, and was practically complete at 12 months. A high-early-strength cement and a white portland cement showed more rapid hydration than standard portland cement. Part 3—Depths of hydration were measured for particles of tricalcium aluminate, tricalcium silicate, dicalcium silicate, and calcium ferro-aluminate. Experiments were conducted at room temperatures, and corrections were made for impurities. Calcium ferro-aluminate was added in small amounts to each of the three minerals to see what effect its presence might have on the reaction rates. No definite effect was noted, probably because of great reactivity of compound itself for water. Calcium sulfate was added in part of the experiments. A few mixtures of minerals were observed, including one roughly approximating commercial portland cement. Tricalcium aluminate was hydrated most rapidly. Tricalcium silicate was not far behind, while dicalcium silicate had a comparatively slow reaction rate. Rates for portland cements were between the two silicates at ages up to 7 days. In general, mixtures reacted more rapidly than single compounds, particularly when calcium ferro-aluminate was added.—GLENN MURPHY

The relation between the strengths of cements developed by mortar specimens and concrete specimens. J. R. DWYER AND P. H. BATES. *Proc. A. S. T. M.*, 1930, Part 2, V. 30, p. 598-614.—Data are presented showing the relations between the strengths developed by several portland cements in various concretes, and in small mortar specimens. The cements were selected as displaying different, but not unusual, strength properties. The aggregates

used were standard Ottawa and Potomac R. sands, and Potomac R. gravel, limestone, and blast-furnace slag. Several water-cement ratios, and three different mixes of concretes were investigated. Ultimate strengths were obtained at 1, 3, 7, 28 days, 3 months, and 1 year. Curves showing relation between concretes and mortars at different ages are rather similar, but values of ratio are in many cases far from identical. Ratio of concrete to mortar strengths varied with age, kind of mortar specimen, and kind, grading, and proportioning of concrete. It follows that ratio will also vary for different aggregates available. These tests indicate that no such ratio can be assumed as holding for the same concretes at all ages or for all concretes at the same age. All concretes in one kind of a mortar specimen develop a strength which has a certain ratio to strength of same cement in a certain concrete, but this ratio changes with ages of testing, and with changes in kind, grading, and amount of aggregates.—GLENN MURPHY

Contribution to the problem of hardening of portland cement. FRIEDRICH F. TIPPMANN. *Zement* (Germany), Dec. 25, 1930, V. 19, No. 52, p. 1225-34.—Hydrolysis of calcium silicates of portland cement clinker, when mixed with water, is complete; end products consist of silica gels and calcium hydrate. It is unessential whether clinker is treated with little or much water. In normal cement mortar mixtures products of hydration are different due to high viscosity of system. Needle crystals formed when cement is treated with excess water are calcium hydrates which are not formed when mixtures of normal consistency are present. Calcium hydrosilicates are not formed, neither in crystalline nor in colloidal form, in hardened cement. All calcium hydrates, separated by hydration of cement, are not present in hexagonal plates or columns but show irregular lamellar shape. Unsoundness is not due to crystallization of calcium hydrates but due to amorphous calcium hydrate which is formed in later hardening periods in case of cements which contain uncombined lime. In this period, gypsum has no influence. Hardening is caused by ideal cooperation of colloid silica and crystalline calcium hydrates which are most important constituents in hardened portland cement. This calcium hydrate is the fundamental factor in hardening process. A microscopic method is described which allows observation of hardening process in cement water mixtures of normal consistency. Unsoundness due to gypsum is caused by excessive crystallization of calcium hydrate when amount of colloids present is insufficient. It is possible to make a cement, which is unsound due to lime, sound by addition of gypsum which converts amorphous calcium hydrate into crystalline form. This can be done within small limits. Several microphotographs are given.—A. E. BEITLICH

Belgian cement industry. G. BAIRE. *Revue materiaux constr. trav. publics*, Jan., 1931, No. 256, p. 17.—Belgian cement industry has shown great progress in recent years, as manifested in improvement of industrial processes and in perfection of material used. Proportioning is done with greater care and raw mix before calcination presents a more intimate and homogeneous mixture. Slurry is of greater fineness. Calcination is much more uniform and effective, so clinker obtained is generally of satisfactory appearance. Milling is also done with greater care. Numerous plants, which heretofore manufactured only natural cement, today produce portland, notably in Tournai region. Progress in specifications from 1897 to 1927—date of latest specifications—has contributed to rising standard of product. A number of plants now manufacture a high test cement whose properties are comparable to fused alumina cement. Prof. Batta, of the University of Liége, is authority for the statistical data in the article. Total production of portland cement in Belgium has grown from 250,000 tons in 1890 to 3,200,000 tons in 1929. Cement industry is one of most important industries of the country. As production greatly surpasses the national demand, the greater part of cement is exported. Belgium has been able to create and hold its markets abroad. List includes

32 Belgian plants. To guard interests of the industry, a professional Association of Belgian Portland Cement Manufacturers was formed. It exercises control over the cement products of all affiliated plants. Products are tested at University of Brussels. Of the 32 plants listed 29 are affiliated with the Association, which lends its mark only to unquestionably satisfactory products. The laboratory also is engaged in research work and attempts to popularize the acquired knowledge on cements, mortars and concretes. Abstracts of specifications are appended.—M. A. CORBIN

MISCELLANEOUS

Communication from the German material testing institutions. Mitteilungen der deutschen material prufungsanstalten (Germany). Verlag von Julius Springer, Berlin. 1930, V. 6-8.—Part A.—Development of other than Prussian material testing institutions. Includes descriptions of laboratories and equipment at the following Institutions: (a) Technischen Hochschule Darmstadt; (b) Technischen Hochschule Dresden; (c) Technischen Hochschule Karlsruhe, two departments, one for concrete and one for wood, stone and iron; (d) Technischen Hochschule München, two departments, one for building materials and one for mechanics; (e) Bayerischen Landesgewerbeanstalt; (f) Technischen Hochschule Stuttgart. Part B. Technical abstracts.—H. G. FISK

Light mortars of pumice and Si-Stoff with portland cement. HEINRICH LUFTSCHITZ. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 55-9.—Properties of cement mortars with pumice and Si-Stoff were examined. One mixture consisted of 1 part of portland cement and 6 parts of pumice (0-0.2 in.) and another one of 1 part of portland cement, 1 part of Si-Stoff and 5 parts of pumice. Si-Stoff is waste product of alum manufacture and contains large amounts of soluble silica. Analysis of Si-Stoff and pumice are given. Mortar with Si-Stoff is lighter, more dense and has better heat insulating properties than first mixture. Its coefficient of expansion is smaller and it is rust preventing. It is suitable for use with steel skeleton structures and for manufacture of light concrete pipes. Mortars for such uses should not contain more than 0.25 per cent water soluble substances.—A. E. BEITLICH

Protection of construction materials against chemical and physical agencies. Schutz der Bauwerke gegen chemische und physikalische angriffe. OTTO GRAFF AND HERMANN GOEBEL. Verlag von Wilhelm Ernst & Sohn, Berlin, 1930, 224 p.—This book is written from standpoint of engineer and chemist, and illustrations and examples are taken from experiences of the authors. It is not advanced as a comprehensive treatise, but emphasis is placed upon numerous problems encountered in field of construction and engineering. Subjects treated are: natural building stones; cementing materials, i. e., limes and cements (portland, etc.); mortar and concrete; masonry construction which includes concrete, reinforced concrete and refractory construction; metals and wood. Under each subject methods of use, or construction, physical and chemical properties, tests, etc., and known methods of protecting or prolonging the life of the material are given. Emphasis is given the proper selection of material for the service to which it is to be put, and proper engineering design and installation of the material.—H. G. FISK

Coloring cement. *Conc. Bldg. Conc. Prod.* (England), March, 1931, V. 6, No. 3, p. 44.—Requirements for cement color pigments are color durability under exposure to sunlight and weather, fine subdivision, intensity of color when finely subdivided, and a chemical composition such that pigment does not react with cement to detriment of the color or cement. The most suitable are iron oxides (red, black, yellow, brown) manganese dioxide (black) chromium oxide (green) carbon pigments (black) ultramarine (blue). Use of organic colors is not dependable. Colors containing Prussian blue, cadmium

lithopone and zinc and lead chromates should be avoided. Brilliant or intense colors are not generally attainable. Carbon black pigments although most effective, cause serious reduction in strength and are difficult to incorporate uniformly when quantity exceeds 2 or 3 per cent of weight of cement. Black iron oxide is better pigment but the cost is rather high. Limit of 10 per cent of cement weight is usually put on quantity of pigments used, although experiments show that in certain cases this limit may be safely exceeded. Most satisfactory way of incorporating pigment is to grind with cement. For delicate tints white cement or a mixture of white and gray, should be used, and such aggregates as silica sand and marble. As far as possible the color of aggregates should harmonize with that of the cement paste. Coloring of concrete has been accomplished by penetration processes, but variations inherent in the absorptiveness of the surface usually cause some non-uniformity of color. It is usual to incorporate a fluosilicate hardener with the color producing salt, the solution being applied after the concrete has been cured and allowed to become surface dry. A final oil wax treatment is applied to fix and protect the color.—JOHN E. ADAMS

PROPERTIES OF CONCRETE

Protection of structures against chemical and physical attacks. "Schutz der bauwerke gegen chemische und physikalische angriffe." OTTO GRAF AND H. GOEBEL. 1930, Wilhelm Ernst and Son, Berlin (Germany), R. M. 22.00. Reviewed in *Zement* (Germany), March 26, 1931, V. 20, No. 13, p. 306.—Authors report in this book various kinds of destructions of structural materials and structures. Effect of chemical and physical conditions is shown by test results, tables and illustrations. Of special value are descriptions of restorations of entire structures showing useful application of experience.—A. E. BEITLICH

Effects of contraction in large concrete dams. ALBERT RENAND. *Magazine Technico* (Argentina), Sept.-Dec., 1930.—Engineers of concrete dam at Saint Marc on Thourian River having in mind dangers arising from formation of contraction cracks in concrete dams have made very careful observations on formation of cracks in that structure during construction. San Marcos dam is gravity type about 140 ft. high and contains approximately 80,000 cu. yd. of concrete. Work was authorized in August, 1928, and first cracks were observed in October, 1929. A number of other cracks were noted later and the progress of these cracks and their location in the structure is given in detail. Colored water was used to trace the penetration of the cracks —C. G. CLAIR AND M. N. CLAIR

Studies on laitance of cement mortars and concrete. SHOICHIRO NAGAI AND KOSUKE YOSHIZAWA. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), Jan., 1930, V. 33, Supplemental Binding, No. 1, p. 19-21B.—In continuation of previous work relations between compositions of laitance and water-cement ratios, admixtures or accelerators were studied. (1) Cement mortars. Results of analyses of laitance formed on 1:2 cement-sand mortars were compared with cements used. Increase in loss on ignition and lime show formation of large amounts of calcium carbonate due to carbonation of calcium hydroxide which was formed during hydration process. High SO_3 was found in cases of large w/c ratios. (2) Neat cements. Similar relations as in (1) were detected. (3) Neat cement with admixtures or accelerators. Siliceous earth, pozzuolana, lime, calcium chloride, "Cal" and gypsum were mixed in different proportions with 2 cements and their chemical composition studied. Amounts of water soluble chlorine and SO_3 were determined. —A. E. BEITLICH

Studies on laitance of cement mortars and concrete—Part 2. SHOICHIRO NAGAI. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), July, 1930, V. 33, Supplemental Binding, No. 7, p. 260-2B.—Results of analyses of chemical compositions of laitances formed on various concrete works using portland cement and of mortars of blast furnace slag cement and high early strength alumina cement are reported. (1) Amount of laitance on 1:2:4 concrete increased with w/c ratio. Laitance on concrete with small w/c ratio was nearly equal in composition to cement while laitance formed with large w/c ratio contained larger amounts of lime in comparison to silica. The SO_3 content increased with w/c ratio. (2) Laitance on field concrete contained large amounts of fine sand. (3) Considerable amounts of SO_3 (5 to 6.5 per cent of ignited sample) were found in laitance formed at concrete pipe making. (4) In laitances formed on high alumina cement (Ciment fondu) and blast furnace slag cement considerably larger quantities of alumina (hydrated alumina from aluminates) were found.—A. E. BEITLICH

Resistance of concrete to high temperatures. (cf. *La Journée Industrielle*, Dec. 20, 1930.) *Le Constructeur de Ciment Armé*, Feb., 1931, No. 137, p. 36.—It has been noted that reinforced concrete construction withstands fires better than steel frame structures. Highly infusible nature of cement and aggregates and no oxidation of exposed steel are advantages of concrete construction. Aside from fusibility, the compressive strength was also considered in tests made in Germany. Parallel tests of portland and slag cement mortars were carried out. Between 500° C. and 900° C., the two mortars showed similar trend of compressive strength. On the other hand, from ordinary temperature up to 300° C. slag cement mortar shows an increase in strength, while portland cement mortar shows a decrease of 10 to 20 per cent of strength values. Between 300° C. and 500° C., strength values show a decrease less rapid in the case of slag cement mortar. Exceptional heat-resisting qualities of slag cement justify use of slag as ingredient in the cement. These considerations are of interest not only in connection with fires, but in all cases of local heats encountered in the industrial processes of today.—M. A. CORBIN

Pre-determination of the composition of concrete necessary to attain a given strength and elasticity. M. ROS. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930. The formula given by Feret enables the strength and elasticity of concrete in compression to be predetermined with sufficient accuracy for practical purposes. It enables recognition of technical and economic possibilities of producing a concrete of definite and suitable quality, consistency, workability, porosity, strength and elasticity. By making use at same time of cement tests with plastic mortar according to Feret's method the whole of the wide field presented by the cement industry is governed by a unified idea. Feret's prism method enables the energy of the cement, the characteristic of the sand and gravel, and the strength properties of the concrete to be determined. In practice the prism compression strength is to be considered as correct strength for concrete. Curves for most favorable intergranular arrangement lie in the area bounded by the Fuller curve and the curve obtained by the Swiss Federal Testing Laboratory (E. M. P. A.).—EDITORS N. I. A. T. M.

Compression, tension and bending tests, cement and concrete. A. T. GOLDBECK. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930. Present practice and trends in methods of making strength tests on cement and concrete in the United States of America are discussed. It is indicated that although the 1:3 mortar briquet, made with Standard Ottawa sand and tested in tension is now standard, there is difficulty in obtaining concordant results in different laboratories. Although the compression test is still most universally used as a standard strength test for concrete, there is a

growing tendency to employ beam tests where high crossbending resistance is important as in highways. Method of making beam test has not yet been standardized.—EDITORS N. I. A. T. M.

Cement and concrete. R. M. STRADLING. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—In a report dealing principally with work carried out at the Building Research Station, Garston, England, a section on strength describes work done on effect of water-cement ratio on strength, recent increase in strengths obtained from rapid-hardening portland cements and relation between crushing strength and modulus of elasticity. Under heading of shrinkage, work on stress distribution along a reinforcing bar, influence of type of cement, percentage of reinforcement and conditions of storage are discussed. A note on the creep of concrete under load, mentions work by Faber, and briefly outlines the program of research in hand at Building Research Station. Joints in concrete and, lastly, resistance of concrete to chemical action, on which work is being done in collaboration with the Institution of Civil Engineers, also receive attention.—EDITORS N. I. A. T. M.

The crushing strength, density and water-cement ratio of concrete and mortar. E. SUENSON. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—The following investigation shows that: (1) Except that the exponent 2 can vary between 1.8 and 3.5, confirmation has been obtained for Feret's formula for plastic mortars, viz: $S = K \cdot T^2_k$, where S is the crushing strength of the mortar, T_k the density of the plastic mass, and K a constant depending on the quality of the cement, the conditions of storage and the age of the mortar. (2) In the form: $S = K \cdot T^n_k$, the equation can be generalized so as to be valid for all consistencies, from the driest to the wettest, provided the determination of T_k is postponed until solidification has occurred. (3) n has the same value for air and water storage. The reason it varies in magnitude as described in (1) remains at present unknown.—EDITORS N. I. A. T. M.

Laboratory tests and control and practice on the building site. M. SPINDEL. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Concrete of any desired quality can be rationally and with certainty produced if due heed is given to our knowledge of the testing of materials. Otherwise, concrete structures, like other structures, can show serious defects. In addition to determining strength and density, tests must be made to ascertain the expansion and shrinkage due to the rise of temperature in setting and variation of air temperature, and the resistance to frost, to attack by water, and to wear. Dam walls must be rendered impermeable by concrete facing. For the attainment of strength and density, the utmost importance is to be attached to cement, aggregates, amount of water, and method of working. The effect of these factors on the quality and cost of the concrete can be indicated by representing cement, aggregates, water and air on the Spindel four-component parallelogram.—EDITORS N. I. A. T. M.

Shrinkage of mortar and concrete. E. V. MEYER. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—A series of experiments was undertaken to elucidate the shrinkage of light concrete, especially the so-called cellular concrete. As is well known this material is produced by mixing together a cement paste and a foam. To attain sufficient strength in this material (which is produced with a density varying from 16 to 70 lb. per cu. ft.) a relatively rich cement mortar must be used, which results in serious shrinkage on drying out. The importance of the various factors which affect this shrinkage is investigated, and the results are as follows: (1) Type of Cement. As was to be expected, there are important differences between various cements. Finer grinding of the same cement gives rise to more pronounced shrinkage. (2) Mixing proportions. By increasing the amount of added sand, the shrink-

age step by step diminishes. This decrease is quite regular for cellular concrete, and the author has advanced a formula for the shrinkage of cellular concrete of different proportions. (3) Added Water. It is established that the shrinkage is increased by increasing the amount of water used. (4) Foam Liquid. The foam liquid has no effect on shrinkage. (5) Storage. Keeping the concrete wet over a long period, followed by intensive drying, increases the ultimate shrinkage; shrinkage is diminished, on the other hand, by mild drying out. The shrinking of cellular concrete products is investigated. Finally it is shown that treatment of the material with saturated steam at 100-180 deg. C. results in a considerable reduction of the shrinkage.—EDITORS N. I. A. T. M.

Influence of frequently repeated load on the formation of cracks and the cracking—Safety of reinforced concrete beams—Einflusz haufig wiederholter Belastung auf die Riszbildung und Riszsicherheit von Eisenbetonbalken. HEIM. *Dissertation an der Technischen Hochschule Karlsruhe* (Germany), 1930, 71 p.—In the first section the author reviews previous investigations. Second part takes up special subjects such as effect of variation in speed of application of load, apparatus, test specimens, and preliminary tests. Third section deals with static loading of reinforced concrete beams and includes measurements of elasticity and determination of tension on columns and beams. Formation of cracks in reinforced concrete beams is also taken up. The fourth section treats the effect of frequently repeated load and includes the investigation of concrete beams with and without reinforcing. Conclusions include: (1) Young concrete under frequently recurring load attains a permanent deformation which exceeds the elasticity. (2) A repeated load which does not exceed half of the static load causing cracking, will not cause cracking even after one million load cycles. With a load equal to three fourths of that causing cracking under static loading, cracking will occur under repeated load. (3) If cracks have already appeared under a certain static load, on changing the same load to a constantly repeated load, a condition of equilibrium will be attained in the cracks before the millionth load cycle is reached.—H. G. FISK

Comparative study of the strength of mortar and concrete under tensile, bending, shear, indentation and compressive stresses. R. FERET. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—The author refers to and confirms the fact that it is first necessary to distinguish between two classes of fundamental resistances, firstly, resistances to compression, indentation and shear, which are proportional to each other, and secondly, resistances to tension and bending, which are also proportional to each other, but bear no fixed relation with the first class. Author then shows, both from personal experience and from analyzing minutely the results of various other experimenters, that in general, for series of mortars and concretes made with the same cement and differing in only one factor, resistance to tension (or to bending) increases less rapidly than the resistance to compression, and varies approximately with 2/3 power of the latter. Otherwise for mixtures of various composition, ratio between first and second of these resistances is approximately proportional to that between the quantities of water and cement used. Disagreement between two classes of resistance is due principally to fact that surface layers of test pieces, which are of first importance in rupture under tension and bending, seldom have same composition as the core. This is due as much to unequal distribution of materials against the walls of the mold and in interior, as to a hardening which varies for various regions, according as the surrounding conditions have a more or less direct influence. Apart from this, resistances are variously influenced by various internal stresses which vary according to distance from free surface, and which result from changes in volume due to chemical, thermal and hygroscopic action. It seems, however, that the tensile and bending tests do not give very accurate information regarding similar forces to which concrete is sub-

jected in practice, although the figures given by compression tests are fairly proportional to the actual strengths.—EDITORS N. I. A. T. M.

Cracks in concrete. M. E. ROSSBACH. *Revue materiaux Constr. Trav. Publics*, Jan., 1931, No. 256, p. 12-17.—Development of cracks in plain and reinforced concrete is consequence of shrinkage of cement and of the low resistance of concrete to elastic stresses, other than compression. As, due to foregoing, concrete is depended upon only in its resistance to compression, its other properties are frequently neglected and a concrete is classed entirely in accordance with its compressive strength. Our daily experience shows failures of concrete in compression are rare, in spite of unreasonable loadings and irrational proportioning of materials. Using standard portland cement and an aggregate of river origin or of porphyry, gives concrete well able to resist usual stresses with required safety. Yet cracking of concrete occurs all too frequently and is main grievance against this material. While compressive strength remains the primary requisite of concrete, attention should be paid to its other qualities. A ductile concrete, least affected by cracking and friction, should be sought. The deplorable appearance of cracks on structures, the menace to life of structure and to reputation of reinforced concrete in general should be kept in mind.—M. A. CORBIN

The cause of poor agreement between tensile strength of neat cement and sand mortar strength. KATSUZO KOYANAGI. *Kogyo Kwagaku Zasshi, J. of Soc. Chem. Ind.* (Japan), Nov., 1930, V. 33, Supplemental Binding, No. 11, p. 425-7B.—Experiments by R. Meade, G. Haegermann and J. Iguchi are discussed. Based on author's investigations, strength of neat cement is just as much affected by amount of mixing water as is mortar strength. Best results in each case are obtained with a certain fixed quantity. Cements which pass water test but not boiling test have in general very high tensile strength in neat specimens and low sand mortar tensile strength. Fineness affects strength of neat cements: coarse samples show in general greater tensile strength than fine cements (while mortar strength is mostly improved by fine grinding). Factors which increase strength of neat cement have adverse effect on mortar strength.—A. E. BEITLICH

Shrinkage of concrete in actual structures. WILLIAM M. BASSETT. *J. Boston Soc. C. E.*, March, 1931, p. 67-81.—Change in volume of concrete must be expected and New England Power Construction Co., has tried to design the Fifteen Mile Falls Lower Development so as to reduce the damage from such volume changes to a minimum. Spillway structure was poured in sections 45 ft. long after a study taking into consideration the possible shrinkage of the concrete as 0.055 per cent of its length, curvature of the bulkhead plant, restraint of bed rock and capacity of concreting plant. A field survey made approximately one year after pouring of concrete showed six out of eight of the 45-ft. sections had intermediate cracks. The cracks appeared in less bulky sections and indicated that if sections something less than 30 ft. long had been used, intermediate cracks would not have formed. Spillway channel slab used for protection of earth bank of spillway channel was built on concrete ribs spaced about 20 ft. centers. Elimination of irregularities on the surface was important as water velocity is high and slabs were therefore designed with 0.5 per cent steel to prevent cracks forming. Recent field examination shows a crack between slabs and ribs and also between slabs and toe beam. Theoretical width of cracks between slab and rib is 0.06 in. and actual width was found to be about same. Theory in design and procedure in construction of intake structure are described in detail. Every effort was made to anticipate and overcome effects of volume change that might result in a crack through which seepage would occur.—MILES N. CLAIR

Tests of plain and reinforced Haydite concrete. (See MATERIALS—AGGREGATES.)

The strength of Swiss portland cement. (See MATERIALS—CEMENT.)

ENGINEERING DESIGN

BRIDGES

Longest multiple-arch concrete highway bridge to span Susquehanna river. CHARLES M. NELSON. *Eng. Con.*, March, 1931, p. 119-122.—River crossing between Columbia and Wrightsville, Pa., has a total length of 7,374 ft., including approaches. The spans of bridge are on a tangent with exception of first span on each side. The river structure consists of 28 concrete arches with three ribs each spaced 17 ft. 9 in. on centers, parabolic intrados and extrados, rise of 32 ft. and 27 ft. 4 in., respectively, and a clear span of 185 ft. The rib section is 7 ft. wide and varies from 3 ft. 10 in. at the crown to 7 ft. at the springing. Each span is divided into 11 panels by transverse spandrel walls. Arch ribs are joined at alternate panel points by concrete struts. Floor system is carried on concrete spandrel columns 2 ft. 6 in. by 4 ft. along the line of outside ribs and 2 ft. 6 in. by 3 ft. 6 in. along the line of the inner ribs. Floor panels are formed by longitudinal and transverse floor beams and are 16 ft. 10 in. by 17 ft. 8 in. Floor slabs are of two-way reinforced concrete. An unusual feature in the floor design is the arrangement and design of expansion joints. Super-structure will be completely separated by open joint 1½ in. wide in floor system and 1 in. in railings at center of first and fourth panels from each abutment or pier. Thus each arch floor system will be cut at four points between piers. Joints are to be filled with bituminous filler and flashed with copper. Roadway is 38 ft. between curbs. There is one 6-ft. cantilevered sidewalk. The approach structures consist of 18 50-ft. concrete girders and two 80 and 85-ft. steel girders, all on concrete piers.—N. H. ROY

BUILDINGS

Design of a 15-story apartment building in Vienna (Austria). *Zeitschrift Oester. Ing. Arch. Vereins* (Austria), Jan. 9, 1931, V. 83, No. 1-2, p. 1-2.—New reinforced concrete skeleton structure of unique design rests on one single reinforced concrete slab foundation. First and second floor are occupied by stores and offices. Apartments are located from third to tenth floor and restaurants occupy tower structure.—A. E. BEITLICH

Storage building with precast roof arches. MANGOLD. *Beton u. Eisen* (Germany), Jan. 20, 1931, V. 30, Heft 2, p. 37-38.—The city of Munich received 37 competitive designs in reinforced concrete, steel and timber for a storage shed for iron water pipes. Reinforced concrete design of Wayss & Freytag A. G. was selected as most satisfactory and most economical. Building is a one-story structure 345 ft. long by 76 ft. wide and 56 ft. high. A crane runway extends the length of structure and 69 ft. beyond, spanning the adjacent street. The girders are roughly I-shaped and carry the crane rail on the lower flange. Girders are about 12 ft. deep with a web thickness of 1 ft. 4 in. and a chord thickness of about 4 ft. They are carried by supports spaced at 69 ft. and with these supports form a series of three three-legged bents along each longitudinal wall. These bents are connected by hinges in the crane girders. Arched roof members, about 1 ft. 6 in. deep with a rise of 15 ft. 9 in. and spaced at 8 ft. 7 in., were precast on the ground and lifted into place by crane. Crown reinforcement was designed to act somewhat as a hinge, and this section and two ends of arch were not concreted until arch was in place. Alternate arches were provided with tie rods to take up horizontal thrust. A reinforced member

extending the length of structure connected arches at crown. The light weight concrete slab between the arches also exerts a stiffening effect. Only scaffolding necessary for roof was a line of timber framing along center of building, supporting crown. Skylights are built between the arches and stop about 10 ft. short of eaves. Glass area is 25 per cent of total roof area. To enable loaded crane to pass out of building a sliding panel between the crane girders and a large folding door are provided at one end.—A. A. BRIELMAIER

DAMS

Cellular corewalls for embankment dams. H. C. HOWELL. *Eng. News Record*, Feb. 26, 1931, V. 106, No. 9, p. 359.—A new type of cellular concrete corewall for embankment dams has been developed by Mexico office of the J. G. White Engineering Corp., consisting of a row of vertical arched cells each of which drains into a longitudinal conduit at the base. Conduit discharges into outfall drains at convenient places. Important features are (1) downstream portion of dam is kept dry; (2) cells and drains permit inspection; (3) cells form stiffer structure than a solid wall (4) arched sides are more economical than flat ones because tensile stresses and necessity for reinforcing steel are eliminated. The idea for the cellular corewall was put into practice in 1917 to 1919 in the construction of the Requena Dam about 50 miles from Mexico City.—D. E. LARSON

Design and economy of concrete and reinforced concrete dams. E. PROBST AND F. TOELKE. *Zeitschr. d. Vereins deutsch. Ing.* (Germany), 1930, V. 74, No. 13-15, 15 p.—Paper, which was presented at second world power conference in Berlin (Germany), 1930, pictures present state of dam construction considering especially safety and economy. Ways are shown to prevent failures. In general, curved form of gravity dams does not increase stability of structure unless contraction joints are filled and treated in manner similar to that in construction of Pardee dam (cf. *Eng. News Rec.*, Feb. 14 and March 21, 1929, V. 102, No. 7 and 12, p. 258-62, 457-8). Study of cross-sections of numerous dams shows predomination of triangular type. Relation between width of dam at bottom and total height is characterized. Development of arch dams is illustrated. Corfino and Turrite dams in Italy are of elastic arch type. Latter dam has constant outer radius of curvature. Wall at crest is 13.8 ft. thick at center and this dimension increases to 19.7 ft. at both sides. As examples of constant angle arch dam type are described Big Santa Anita, Pacoima and Diablo dams (cf. JOURNAL, A. C. I., Sept., 1930, *Proceedings*, p. 1-64). Latter has two gravity abutments. Attention is called to gradual thickening of foundations on downstream side of dams. Mesnager builds a number of arch dams, decreasing in height, between each two of which a water reservoir is formed. Walls can be built relatively thin. A new type of dams designed by authors is described. Its lower part is of gravity type while upper part is arch structure. Gutzwiler, Figaro and Ziegler systems are sketched. Concrete structure of Stony Gorge dam in California is of Ambursen type. (cf. *Eng. News Rec.*, July 11, 1929, V. 103, No. 2, p. 46-51.) Main advantage of this type is even distribution of loads on underground. Buttress spacing over 18 ft. is not economical. Big Dalton dam is described as an example for multiple arch type dam with double wall buttresses (cf. *Eng. News Rec.*, Dec. 26, 1929, V. 103, No. 26, p. 994-7). Formation and causes of cracks are discussed in connection with those structures. Third part of article deals with safety and economy and gives general directions concerning foundations, calculations, structural materials and recommendations for research work in dam construction. Great emphasis is placed on temperature measurements in interior of large concrete masses.—A. E. BEITLICH

Gravity dams arched downstream. B. J. LAMBERT. *Proc. Am. Soc. C. E.*, March, 1931, V. 57, No. 3, p. 425.—It has been a common practice to arch masonry gravity dams upstream with the thought that additional factor of safety was introduced by arch action. When walls of canyon are not sufficiently rigid to support thrust, there is no gain from arch plan over a straight gravity dam. In such cases stability of a straight gravity dam against overturning may exceed that of a gravity dam of same section that has been arched against water load and a dam arched downstream may have a stability that exceeds either. In illustrating this point the author makes use of measurements and calculations from a 1/240 scale model of the late St. Francis Dam. In his analysis he treats the structure as a unit and shows that the portion of dam about which overturning would occur (the pivot) lies farther from the centroid for gravity section than for section arched upstream and farther for section arched downstream than for either. Length of dam that can act as a pivot again favors reverse arch. The objection that reverse arch plan would tend to open up rather than close joints is considered and it is suggested that anchored eyebar chains under initial stress could be embedded in concrete of dam to develop any desired initial compression in the concrete. While admitting unorthodox nature of recommendations the writer urged that in any case preliminary studies should be made on a model of proposed site and structure.—H. J. GILKEY

Problems in concrete dam design. D. C. HENNY. *Eng. News Record*, March 12, 1931, V. 106, No. 11, p. 431-435.—Wide differences of opinion regarding fundamentals of safe and economical design of concrete dams still exist. Danger inherent in uplift is now thoroughly realized by dam designers and builders and means of reducing its effect are: roughening rock base and concrete surfaces to increase adhesion and resistance to water creep and sliding; grouting foundation; introducing drains in foundation and mass concrete; inclining or stepping construction joints upwards in downstream direction; using water stops in these joints near upstream face. Grouting upstream toe of dam does not guarantee against uplift but helps to diminish it. Drains in foundation rock and in concrete are now commonly provided, but requirement that these be straight and accessible is too often neglected. Principal cause for extensive cracking in large dams may be tendency of cement manufacturers to increase fineness of grinding. This affords advantages in workability, early strength and form cost, but in mass concrete important effect is greater heating and consequently an increased liability to cracking. Heat control may be effected by amending cement specifications. Another method of heat control consists of artificial cooling of interior by water circulating through pipes. Problem of heat stresses and cracking in dams can be solved by use of precast concrete blocks. This would reduce cost of form work, but cost of handling would be high.—D. E. LARSON

MISCELLANEOUS

Stands of novel design at English race course. *Concrete*, Feb., 1931, p. 95.—The stands at Northolt race course are of steel and concrete. The roof deck is carried by cantilevers of steel encased in concrete. Cantilevers extend 60 ft. forward from the back of the stand.—N. H. ROY

Short-cuts in structural design. JAMES R. GRIFFITH. *Concrete*, Feb., 1931, p. 45-48.—Unbalanced reinforcing is discussed for the case of concrete beams and slabs whose dimensions have been determined by considerations other than that of producing maximum allowable stresses in both concrete and steel. A chart is given for determining actual concrete stress and area of steel required, for a breadth of 12 in. and f_s of 18,000 lb. per sq. in. A second chart is for f_s of 20,000. Three values of n are given.—N. H. ROY

Calculation tables for hollow concrete brick ceilings. HANS KORF. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 61-3.—A graph is described which enables one to read directly thickness of bricks, total thickness of ceiling and size of reinforcing when span, load and type of support are given. Several examples explain use of graph. It can be applied to ceiling systems by Ackermann, Kleine, Wenko and Remy. Reverse reading of table gives greatest span for certain ceilings of given dimensions.—A. E. BEITLICH

Structural design and construction of concrete improved in 1930. *Concrete*, Feb., 1931, p. 16-18.—A very interesting bibliography of technical papers, results of tests, committee reports, and contributions to the field of design for the year 1930.—N. H. ROY

Concrete bulkheads for creek channel improve Jacksonville swamp area. *Eng. News Record*, Jan. 8, 1931, V. 106, No. 2, p. 70-72.—The unsightly Hogans Creek Swamp at Jacksonville, Fla., has been changed to an attractive waterway built of concrete as result of a $500,000 improvement program recently completed. Design of channel structure finally adopted provides for a box 20 ft. wide on two rows of wood piling, 18 ft. apart, with piles driven on 5-ft. centers. A 6 x 8-in. cap runs longitudinally over top of each row of piles. Precast concrete T-beam struts span the two rows of piling on 5-ft. centers. Each end of the struts carries a 6 x 8-in. longitudinal wooden stringer, and upon these stringers rest precast slab units that form sides of box. Two-in. planking is then placed longitudinally under the struts and the bottom of the box is filled with sand to the depth of 2 in. above the top of the strut, which provides a porous floor system for admission of groundwater to channel. Bulkhead panel lengths vary from 6½ to 9 ft. and are precast in 2-, 4-, and 6-ft. widths. The 6-ft. widths are used generally except on curves. Gang molds are used in casting yard where bulkhead panels and T-beams are cast. This yard permits casting of 150 lin. ft. of bulkhead and 21 T-beams at same time. A central mixing plant provides all concrete for the job, for both precast and cast-in-place work. A minimum strength of 3,000 lb. is specified and obtained under laboratory conditions.—D. E. LARSON

Reinforced concrete. S. M. DIXON. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Exact knowledge of the properties of concrete especially in reinforced concrete structures is meager. Innumerable tests on compressive strength of concrete have little advanced accuracy in design of reinforced concrete beams. Experimental work on shrinkage, expansion, modulus of elasticity and plastic yield is still needed. Disintegration of plain concrete under repeated loading makes continued security of some reinforced concrete structures problematical. Engineers are much interested in stresses induced in steel during setting of surrounding concrete, and tests so far are hardly conclusive. Recent design has been much influenced by special light aggregates or by using aerated cement.—EDITORS N. I. A. T. M.

Tests on reinforced concrete structures. R. SALIGER. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—In the years 1927-1929 the following tests were suggested by the writer of this report and performed at the Engineering Testing Laboratory of the Polytechnical Institute of Vienna. In 1927 tubes for the power-station of Blumau and also a new shellroof system, suggested for the barrelwashing-shop of the brewery of Schwechat, were tested. Both these series of tests were performed on full-sized models. In 1928, experiments were carried out on concrete beams reinforced with Isteg-steel. They showed the influence of two round iron bars twisted cold, while during twisting the ends of the bars are rigidly held in their places. These experiments were followed by tests on beams of concrete, reinforced with high-quality steel, and others on pillars of concrete reinforced with cast iron and corded with steel. In 1929 a series of tests on concrete pillars reinforced with high-quality steel, yielded important results.—EDITORS N. I. A. T. M.

Combined compression and bending in reinforced concrete. E. M. ROYDS-JONES. *Concrete Constr. Eng.* (England), Feb., 1931, V. 26, No. 2, p. 144-149.—Charts are given for determining thickness of concrete and amount of reinforcing steel necessary in slab or beam subjected to combined bending and compression for cases where concrete is not stressed to a specified allowable stress. This is the case where the size of member is fixed already by other considerations. Example shows application of charts. Total moment of external forces about steel is obtained for beam of known dimensions, bending moment and end compression. Then $H = M/bd^2$, where M = moment of forces about steel, b = width and d = depth of beam. From graph value of stress in concrete obtained for calculated value of H and selected value of stress in steel. Curves are given for different stresses in steel. With value of stress in concrete thus obtained a second graph gives values of k (ratio of depth to neutral axis, to depth to steel) for given allowable stress in steel. Then compressive stress in concrete $= 1/2 f_c kbd$, tension in steel and required area of steel are obtained. Examples illustrate the usual general case, case where concrete dimensions are too small, and where no tensile steel is required.—JOSEPH MARIN

Deformation of the reinforcement as a measure of its value in ferro-concrete. E. H. F. EMPERGER. *First Communications of N. I. A. T. M.* Group B, Zurich, 1930.—Investigation of ferro-concrete has been limited to measurements under permissible load and determination of breaking loads. The connection between the two has been represented by a theory which cannot be regarded as free from objection: that enclosed steel is constrained to deform with the concrete, and that the measurement of this deformation in the case of the reinforcement of a beam in tension enables the stress taken by this reinforcement to be determined, so that the variation of the quantity n as load increases can be evaluated. The relationships under compression are much simpler. Parallel experiments on concrete columns, with and without reinforcement, are used to determine the increase in strength due to the reinforcement under same deformation of concrete. These tests show that reinforcement which is not proof against buckling does not withstand compression as well as the surrounding concrete. The feeble round steel rods yield sideways, and do not contribute to the strength of the member to an extent corresponding to the magnitude of their deformation, even when they are held within a circular reinforcement. The most important result of this research is that by the use of a buckling-proof reinforcement of cylindrical profile, within a circular reinforcement, full utilization can be made of the strength of the steel under compression up to the yield point, with similar utilization of the concrete. It is also possible in this way to utilize the much higher yield points of high-strength steels.—EDITORS N. I. A. T. M.

Solution of statically indeterminate structures by Begg's method. K. SCHOECHTERLE. *Beton u. Eisen* (Germany), Nov. 20, 1930, V. 29, Heft 22, p. 406-410.—In brief review of theory and application of Prof. Begg's mechanical method of solving statically indeterminate structures, the last section describes experience of Stuttgart office of Bridge Dept., German Government Rs., with this method. This office, in 1927, designed and erected a concrete arch bridge at Weikersheim, with a span of 90.0 ft. and a rise of 27.6 ft. It was decided to compare results of a mechanical solution with completed analytical analysis of this structure. Preliminary tests with models bearing a size ratio of 1:25, 1:50 and 1:100 to the original structure showed that the 1:50 ratio was most satisfactory for this arch. A model in 0.08 in. was accordingly made in this size ratio. Influence lines comparing results of analytical and mechanical solutions for moments, shears and thrusts at crown and springing show remarkably close agreement. In this case mechanical solution must be considered equal to analytical. Thorough and critical investigation made of this method led to conclusion that it is applicable to practical use.—A. A. BRIELMAIER

Nomogram for calculating the compressive and tensile stress produced by a force acting on a rectangular section. JORGE QUIJANO. *Ingenieria* (Mexico), Jan., 1931, V. 5, No. 1, p. 8-9.—An alignment chart, one of a series of value in design of concrete, for determination of stress at any point on a section subjected to a force perpendicular to that section, acting on an axis of symmetry. Left hand scale or line $\frac{12\ pr}{a^2}$ intermediate scale R; and right hand scale P/ab all in metric units. a and b are dimensions of the section on which the force P acts. p and r are abscissa respectively of point where force P intersects section and of point where stress R is desired.—C. G. CLAIR AND M. N. CLAIR

Nomogram for calculating the unit shear by means of bending moments. JORGE QUIJANO. *Ingenieria* (Mexico), Jan., 1931, V. 5, No. 1, p. 16-17.—An alignment chart, one of a series of value in design of concrete, for the determination of shearing stress at any section of reinforced concrete beam. Left hand line or scale bd; intermediate scale $\frac{M_A - M_B}{S}$ and right hand scale u. b and d are the dimensions of the section, M_A and M_B the moment at points distant S apart and u is unit shearing stress, all in metric units.—C. G. CLAIR AND M. N. CLAIR

Short cuts in designing reinforced concrete beams. ODD ALBERT. *Civil Engineering*, April, 1931, V. 1, No. 7, p. 635-37.—The amount of work involved in the design of concrete structures may be reduced either by using more simplified formulas or by use of tables and charts. Formulas are presented for rectangular beams in a simplified form makin; it possible to solve for depth with one movement of slide rule runner. Charts for the design of beams and flat slabs of reinforced concrete are also presented. In working out these formulas and charts, it was assumed that variation of stress to deformation of concrete in compression is a straight line and concrete in tension was neglected.—D. E. LARSON

Circular culverts. W. S. GRAY. *Concrete Constr. Eng.* (England), March, 1931, V. 26, No. 3, p. 213-219.—Uncertainty of distribution of loading on an empty culvert or subway is pointed out. Upward reaction differs according to method of construction adopted. There may be a uniformly distributed upward reaction, line contact and concentrated reaction, or a reaction distributed over a saddle in contact with a segment of pipe. In small culverts the reinforcement will generally be the same at all parts. Expressions given for combining moments due to uniformly distributed downward, upward, and lateral loads, moments due to active earth pressure can be found. Expressions are given for case of loads concentrated at opposite ends of vertical diameter. Moment thrust and shear for any section are obtained, similiar to calculations for stresses in a circular ring. Castigliano's principle of least work is applied neglecting the internal work due to normal and shearing stresses. Expressions are given for bending moment and thrust for any point due to the dead load of pipe and for uniformly distributed load. Curve shows variation in moment coefficients along circumference of pipe. Curve also plotted showing variation of thrust coefficients along circumference of pipe. Expressions for moments and thrusts are given for cases of two radial forces symmetrically arranged and of two vertical loads symmetrical about vertical axis of pipe.—J. MARIN

ROADS AND PAVEMENTS

Concrete street construction in Camlenwell, Victoria. C. M. B. NEYLON. *Commonwealth Engineer*, Dec., 1930, V. 18, No. 5, p. 188-193.—Following a visit of S. M. Goldsworthy to America in 1924, the council has undertaken an extensive program of concrete street construction. Concrete

roadway is 20 ft. wide between curbs which are 6 in. wide and 6½ in. high (to permit of 2-in. surfacing of asphaltic concrete at a later date). Crown is 3 in. and thickness of roadway 7 in. Foundations are prepared by mixing ashes and sandy loam 3 in. thick and adequate drainage of the subgrade is insured by drains. Importance of reinforcements at weaker points as corners, joints, etc., is stressed. Thermal expansion and that due to variations in water content were allowed for at the rate of ½ in. per 100 ft. Joints were made slightly wider in the curbs. The mix was 1:5.6 by volume, based on Abrams' fineness modulus but was altered to suit variations in material. Slump was about 1 in. and gave 28-day strengths of 3,300 to 3,800 lb. per sq. in. Screeding was done against the grade. Changes of grade were eased off by ordinary vertical parabolic curves.—C. A. JORSS

Concrete roads, past, present and future. S. H. WALKER. *Structural Eng.* (England), Feb., 1931, V. 9, No. 2, p. 55-64.—In a discussion of progress in the art of road building the disadvantages of joints is pointed out. The Illinois Bates Section is shown with excerpts from various reports presented at Sixth International Road Congress. Since British roads are subjected to extremely heavy traffic, with axle loads up to 28 tons and with steel or hard rubber tires, the importance of smooth joints is far greater in Great Britain than in America. A patented interlocked joint was developed to improve joint efficiency. An apparently crackless concrete road, free from opening and closing joints, has been built from a design of C. P. Courtenay, Borough Engineer, Greenwich. Details are given for this road which consists of a reinforced grooved concrete base topped by a 9-in. thick plain concrete road crust. Grooves which key road crust to base cause invisible closely spaced cracks. Preparation of the sub-grade varies with the soil conditions. Mr. Courtenay's design has been patented as "Anchorete" concrete road. Further application of "Anchorete" plan has been made to resurfacing of old roads.—V. P. JENSEN

The bureau of public roads. THOMAS H. MACDONALD. *Civil Engineering*, March, 1931, V. 1, No. 6, p. 494-496.—Article contains an interesting description of studies of cement concrete made by the Bureau of Public Roads, including measurements of expansion and contraction of concrete due to temperature and moisture change; determinations of effect of alternate freezing and thawing, both during and subsequent to setting period; determinations of effect of time of mixing in full-size paving mixers on strength and uniformity of product; the effect of alkali salts in soil and water on concrete; and means of protecting concrete against alkali attack by bituminous paint coats. Other useful studies deal with effect of kind and proportion of coarse aggregate upon strength and density of resulting concrete. Nearly all concrete pavement curing methods thus far proposed have been tested in an investigation carried out on a section of Tennessee highway 15 miles long. One-half of pavement throughout entire length of road was cured with wet earth and character and behavior of concrete thus treated have been taken as standard of comparison by which relative effects of other curing methods used on the other half of pavement have been determined. In an effort to rationalize design of concrete road slabs, the bureau has experimentally evaluated practically every factor involved except important one of subgrade support. Experiments have yielded all necessary data with reference to contraction, expansion, and warping of slab under various conditions of temperature and moisture. Coefficients of friction between slab and various subgrades have been determined, and distribution of pressure to subgrade from loads applied at various points on pavement measured by soil pressure cells. Related effects upon pavement stresses of joint spacing, subgrade friction, and kind and position of steel reinforcing have been fully explored; and, finally, distribution of stress induced in slab by applications of static loads and impact forces has been studies to a definite conclusion, qualified only by undetermined influence of subgrade variation.—D. E. LARSON

ARCHITECTURAL DESIGN

Build business district of concrete in residential suburb. *Concrete*, March, 1931, V. 38, No. 3, p. 16-17.—Monolithic concrete, concrete masonry and stucoo with cast stone trim are being used in construction of Texas suburban commercial center, in conformity with architecture of Spanish village. Arched entrances and stone doors are reproduced in cast stone with travertine finish. All stone is dry tamped. Finish is obtained by sprinkling rock salt into molds before facing is placed and tamped. During curing salt is dissolved by frequent washing. Holes remaining provide rugged, porous finish. Pleasing color obtained by using white portland cement with coarse, whitish Texas stone and river sand, proportioned 1:1½:1½.—C. BACHMANN

Form details and practice developed for architectural concrete. *Concrete*, March, 1931, V. 38, No. 3, p. 39-42.—Clear cut lumber and fiber board form lining were used in Pacific Coast buildings. Lining was used on all form work intended for flat wall faces. Corners were rubbed down with sandpaper and surface coated or greased with form oil and wiped off. Vertical beveled strips used to obtain fluting were made from kiln-dried spruce, planed, and grain filled with lead and oil before being nailed to forms. Mixing proportions ranged from 1:2½:3½ to 1:2:3, with slump of 4 to 5 in., and 7 to 8 in. for architectural concrete. Horizontal straight lines were obtained at day's work plane by tacking dressed 2 by 2-in. horizontal strip within wall form, against outer face, and at level where concreting is to be stopped for day. Fresh concrete was then placed to a level about ½ in. above lower face of strip and sloped downward toward inner face of wall. About two hours later strip was removed and entire surface of concrete cleaned with stiff broom. Forms were removed six or seven days after concreting. Following removal, exposed surface were given wire brushing to remove fins and films. Waste molds were left in place until building was practically completed when decoration was cleaned with wire brushes and allowed to dry out until uniform in color, followed by fine dash of colored stucco or oil stain, for polychrome effects. Patching mortar proportions were same as for concrete.—C. BACHMANN

Technique and form in cast stone. E. HEMMINGER. *Beton u. Eisen* (Germany), Oct. 20, 1930, V. 29, Heft 20, p. 362-364.—Artificial stone with its manufacture based on wide experience and scientific investigation must be accepted as a satisfactory building material—technically and economically. A recent pamphlet, (*Der Betonwerkstein* by Bund der Deutschen Betonwerke E. V.), is referred to for detailed information on the properties and advantages of artificial stone. Adaptability of cast stone has made it especially suited to lines of modern architectural design. Effects obtained with various aggregates offer a wide range of possibilities in color schemes. Different surface treatments present many variations in appearance. Cast sculpture or cast ornaments may be employed to emphasize portions of a structure or to relieve an otherwise monotonous elevation. A comparatively large market is presented in the field of garden and cemetery architecture. Benches, springs, statues, arbors and monuments may be constructed of cast stone since the modern product has shown itself to be a durable weatherproof material. The time of cramped imitation of natural stone is past and the new material is developing a style and form of its own. Its nature makes it available for designs for which other building elements are unsuited. The latest use of cast stone which has been forced to overcome some resistance on the part of conservative authorities is in church architecture. The Frauenfrieden Church in Frankfurt, A. M., is one of the striking instances of the employment of cast tiles for exterior facing. Interior equipment such as altars, baptismal fonts, etc., may be designed very effectively in cast stone.—A. A. BRIELMAIER

FIELD CONSTRUCTION

BRIDGES

Ancient bridges and their preservation. STEVEN NORRIS. *Roads Rd. Constr.* (England), March 2, 1931, V. 19, No. 99, p. 79.—Various means of renovating and reconstructing ancient bridge into a condition of traffic efficiency were applied without detracting from the bridge's authenticity as an ancient monument. First method is that of lining voussoirs of arch and faces of the abutments with a strengthening shell either of reinforced concrete, concrete or masonry. New arch is formed below existing arch and the existing abutment thus stiffened, the new facing taking some of thrust. New footings for lining wall will probably be required but if not possible then corbels may be tied into the old abutment to take reactions. Finished lining may be stepped or splayed off 4 or 5 in. from the external face of bridge. The second method consists of removing road surface down to arches, repairing and rejointing them where required and packing concrete from haunches to crown level, and reinstating road surface. If this method raises crest of bridge inconveniently high, coping of parapets may be raised by inseting a course or two of well weathered masonry from old local walls, etc. Further stiffening of the arches below may be supplied by erecting two or three arch ribs in masonry, concrete or reinforced concrete, below the arches; the ribs being well keyed to the existing masonry. The third method consists of the demolition of one half of the bridge floor or brick arches at a time, without in any way disturbing the external faces or parapets. The arches are then rebuilt entirely in any form desired. The abutments and piers should be thoroughly overhauled, repaired and grouted where required before erecting new arch centering. Arched slabs between piers and abutments, or springing from new lintels laid on the pier walls, or reinforced concrete girders at 2 or 3 ft. centres, supporting flat precast slabs may be employed. The fourth method is for use when the bridge is too frail to act in any way towards supporting modern traffic. The old bridge is retained merely as a shell to the new and entirely self-supporting structure built above the old arches. A new reinforced concrete single span arch is built and supported on new abutments behind old abutments. Old bridge may be employed to support weight of the centering. In fifth method when the old bridge only needs considerable stiffening, two or three narrow trenches are cut through the floor of the bridge. Centers are erected and the new separate single span arch ribs are constructed springing from the old abutments or new ones behind. —JOHN E. ADAMS

BUILDINGS

Experiences with aerocret-gas-concrete. WERNER. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 63-4.—Experiences with a light concrete during construction of large dwelling house, are given. New material shows great advantage over ordinary concrete for certain purposes. Insulating properties for heat and sound are exceptionally good. Handling of large size stones is very easy. Plaster adheres very well to porous material.—A. E. BEITLICH

Well foundations for construction of several buildings of German Museum in Munich (Germany). KARL BAESSLER. *Report 33rd main meeting German Concrete Association*, March 17, 1930, p. 409-30.—Design and method of construction of foundations for 2 large reinforced concrete buildings embodied new interesting features. Location of structures is on island in river Isar where underground conditions are extremely bad. Several layers of marl, sand and gravel, with 12-ft. loose materials, are on top of sound blue clay. Drillings were made to depths of 82 ft. to investigate bearing capacity of underground. Great variations in this direction led to construction of concrete

piers in open wells. Cylindrical piers are from 3.28 to 4.10 ft. in diameter and 32.8 to 39.7 ft. deep, belled out at base to 9.8 ft. in diameter. Twelve rotary tower drills traveling on top of wells were in operation. Steel tubes were from 4.9 to 6.6 ft. long and thickness of walls was 0.4 in. Loose materials were removed by streams of water, while grabbucket dredge was used for harder strata. Bell shaped excavations for footings were made by hand with compressed air shovel. Concreting was by continuous shoveling of plastic mixture until ground water level was reached. After pulling steel tubes remainder of concrete was placed thus preventing washing out of cement by ground water. Tops of 500 piers were connected with horizontal reinforced concrete girders which support basement walls. Only 2 piers had to be replaced.—A. E. BEITLICH

Winter concreting with use of gas burners. V. SMITKA. *Beton u. Eisen* (Germany), Nov. 20, 1930, V. 29, Heft 22, p. 404-406.—Construction of office building for "Berg und Huettengesellschaft" in Prague continued through unusually cold winter of 1928. Building has a ground area of 26,900 sq. ft. with three sub-basements and required an excavation varying from 33 ft. to 53 ft. below street grade. Two measures were adopted to insure satisfactory concrete: protection of site with temporary wooden enclosures, and heating of aggregate. Temperature in these temporary sheds was maintained at about + 36° F. by means of stoves, while the outside temperature occasionally dropped to — 15° F. The aggregate was placed in the mixer in frozen condition. A six nozzled, fork-like fitting was connected to the city gas line and the flames directed into the upper part of rotating mixer drum. No cement or water was added until the aggregate had reached a temperature of 98° F. to 107° F. A curve was made giving the time of heating required for aggregate varying from + 14° F. to + 86° F. in temperature on arrival at the mixer. The curve is almost a straight line and calls for a heating period of zero minutes for aggregate at 86° F. and 5½ minutes for aggregate at 14° F. When the aggregate had been heated, flame was shut off and unheated water and cement added. Total time in machine could have been reduced by adding cement to frozen aggregate and allowing mixing to proceed simultaneously with thawing. Increased production could be obtained by using two mixers, one being employed only for heating purposes. Prof. J. Klokner made a study of the effect of the temperature of mix at pouring, on the compressive strengths of test cubes and found that a 41° F. mix developed 8-day strength of 910 lb. per sq. in. and a 68° F. mix 1710 lb. per sq. in. It is indicated, however, that this difference in strength decreases with time. Method of heating aggregate proved very satisfactory and has great advantage of permitting concreting to begin without delay caused by elaborate preliminary work. It is desirable to heat aggregate to highest possible temperature and to lower temperature of temporary enclosures accordingly, within reasonable limits, since the first procedure is simple and cheap while the second is difficult and expensive.—A. A. BRIELMAIER

Build business district of concrete in residential suburb. (See ARCHITECTURAL DESIGN.)

Form details and practice developed for architectural concrete. (See ARCHITECTURAL DESIGN.)

DAMS

Foundation procedure at Owyhee dam. *Eng. News Record*, Jan. 29, 1931, V. 106, No. 5, p. 178.—Foundation problems, complicated by necessity of excavating and concreting a fault zone 190 ft. below stream bed, have been solved at 530-ft. arched-gravity dam being built for the Owyhee project in eastern Oregon, and concrete placing on the main structure is well started.

Completion of the removal of the 38,000 cu. yd. of material from the crevice in the fault zone permitted concreting operations on a full scale, and about 1,000 cu. yd. per shift are being placed in the structure from an 8-cu. yd. bucket handled by overhead cableway. In May, 1930, the 250-ft. open cut 50 ft. deep representing the length of the fault zone lying under the dam was filled with concrete. Five 12 by 12-ft. openings were left to permit excavation of the faulted material below. As excavation was completed in various section along the bottom of crevice, the timbering was removed and space filled with concrete. The granite aggregate is shipped 25 miles to washing, screening, and mixing plant, located about ¼ mile from the dam. The entire plant is designed to produce 1,000 cu. yd. in 8 hr. Proportioning the mix has as its objective production of a finished concrete, which is an economic balance between the qualities of strength, impermeability, and durability, with due regard for desirability of using all coarse aggregate brought to the site. Use of 1 bbl. of cement per cu. yd. gives a mix varying from 1:2.7:6.45 to 1:2.5:6.65, and a water-cement ratio of 0.9. The time of mixing is 1½ min. The 28-day strength averages 3,500 lb. per sq. in. Concrete pours are in 4-ft. lifts between radial construction joints. A period of 72 hr. is required between pours on the same section. Bond is insured by washing and cleaning the surface between pours. Provision is made for grouting the construction joints later under a pressure of 100 lb. per sq. in.—GLENN MURPHY

The Chute a Caron hydro-electric development. JAMES W. RICKEY. *Proc. Eng. Soc. Western Pennsylvania,* Jan., 1931, V. 47, No. 1, 43 p.—Details of power developments in Province of Quebec with description of drainage basin are given. Methods for concrete construction have been very completely described by I. E. Burks (cf. JOURNAL of the Am. Con. Inst., Feb., 1930, *Proceedings*, V. 26, p. 315). Of outstanding interest was use of precast obelisk of heavy reinforced concrete for diverting river. While work was going on a large reinforced concrete mass was built on the mid-channel island. Special provisions were made in its pedestal to allow blasting away one of supports to cause obelisk to tip into and block the main channel, thus diverting entire flow up to 50,000 sec. ft. into completed diversion channel and thus permitting construction to proceed on main dam in old river bed. The problem included many unknown factors, such as best way to start obelisk falling, effect of impact against surface of water, possible destruction when obelisk landed on river bed, etc. Extensive mathematical analyses were first made and a model built in hydraulic laboratory of Carnegie Institute of Technology on scale of 1 to 50 to represent section of Saguenay River, diversion channel and obelisk. By means of special recording devices, all mathematical analyses were checked and effect of water action in deflecting and cushioning obelisk were determined in the laboratory. Work done in laboratory was repeated in actual construction and data are given to show that prediction in laboratory was fulfilled when obelisk was upset into river so closely that the final resting place was within ¼ in. of pre-determined location.—P. J. FREEMAN

Zschopau dam near Kriebstein (Germany), a cast concrete job. SUTTER. *Report 33rd main meeting German Concrete Association,* March 17, 1930, p. 467-78.—Zschopau dam, completed in 1929, is concrete gravity dam with total height of 108.3 ft. It is arched on a 738 ft. radius. Crest is 787.4 ft. long and 13.1 ft. wide; greatest width at base is 72. ft. Spillway is arranged in two sections, each having 4 openings 22.9 ft. wide and 13.1 ft. high. All are provided with gates operated from top of dam. At base of dam water passes through three 8.5-ft. pipes with gates capable of discharging about 400 cu. yd. of water per second. Three turbines with an efficiency of 80.5 per cent produce about 8000 h. p. Expansion joints are provided at 65.6 and 82.0 ft. intervals. Copper sheet and asphalt packing were used to make them watertight. Drainage system consists of vertical drains spaced at 6.6 ft. intervals,

which are connected with horizontal drain tile. Concrete was made of mixture of 440-lb. portland cement and 165-lb. trass, special consideration being given to proper gradation of aggregates. Their composition was: 15 per cent sand (0-0.08 in.), 15 per cent sand (0-0.28 in.), 40 per cent gravel (0.28-1.2 in.) and 30 per cent broken stone (1.2-2.4 in.). Central concrete mixing plant was built on left side of river and aerial cableway of 1 mile transported structural materials to construction site. Four 1-yd. mixers discharged into buckets which delivered concrete to 4 distribution towers. (cf. Kirsten, *Bautechnik* (Germany), March-April, 1930, V. 8, p. 149, 233, 247.)—A. E. BEITLICH

MISCELLANEOUS

New German specifications for reinforced concrete. *Zement* (Germany), Jan. 22, 1931, V. 20, No. 4, p. 84-6.—Changes and improvements in new tentative German specifications for construction of reinforced concrete structures especially emphasize improved structural materials and new experiences in field of concrete composition and working.—A. E. BEITLICH

Precast units in slab construction. R. RALL. *Beton u. Eisen* (Germany), Oct. 20, 1930, V. 29, Heft 20, p. 370-373.—A review of precast slabs, beams and hollow tiles used in Germany today gives details of manufacture for various types. Reinforced roof panel of "asbestos-concrete" is one of the new developments. This panel, either flat or corrugated, is used on spans of about 4 ft. Because of the weight of ordinary concrete, panels are usually precast of light weight concrete and used only for roofs. Types cited are reinforced in one direction and vary in thickness from 2½ to 5 in., with spans up to about 8 ft. Various profiles are in use for precast beams. These are either placed side by side to form a slab, or are spaced up to 2½ ft. apart and slab units placed or poured between them. These beams are available for spans up to 20 and 25 ft. The Visintini truss is one of the best known beams. Several tiles for one-way and two-way slabs are shown. Some standardization of practice in span lengths and concentration on certain types are necessary for further development of this field of precast products.—A. A. BRIELMAIER

Modern construction engines. *Zement* (Germany), Jan. 15, 1931, V. 20, No. 3, p. 64.—New engines of great efficiency which are capable of handling very large quantities of materials were used for construction of large channel to river Rhine between Basel (Switzerland) and Strassburg (France). Dams are about 150 ft. wide and are built with modern elevating graders which discharge materials directly upon embankment. Areas ranging from 1,800 to 2,400 sq. yds. can be planed in 8 days. Concrete mixer and distribution system travels on same tracks and places 314 to 392 cu. yd. of concrete in 8 hr. Reinforcement is placed by same engine.—A. E. BEITLICH

An overturned 19,000-ton caisson successfully salvaged. *Eng. News Record*, Feb. 12, 1931, V. 106, No. 7.—During the construction of the piers for Mid-Hudson Bridge at Poughkeepsie, N. Y., one of the caissons tilted to 42½ deg. with the horizontal, necessitating considerable amount of labor in righting it. Each of two caissons, the largest on record, consisted of a concrete-filled steel cutting edge and truss system 60 by 136 ft. and 20 ft. deep with semicircular ends. The lower steel sections were fabricated and towed to the site, where they were filled with concrete. During filling and sinking of east caisson, the weakened clay walls suddenly gave way causing the caisson to lean and settle. Steps were immediately taken to prevent further movement by anchoring it to tugs, and by dumping gravel on the weakened clay bank. Caisson was finally righted by excavating material under high edge and applying a pull of 1,500 tons to top edge.—GLENN MURPHY

Concrete plant in Boston designed to eliminate production delays. W. E. TRAUFFER. *Pit and Quarry*, Feb. 11, 1931, V. 21, No. 10, p. 55-57.—Forsyth Street plant of Boston Transit Mixers, Inc., Boston, Mass., built entirely of concrete and steel requires only six men for operation. The com-

pany has another concrete plant at Roslindale, with capacity of 55 cu. yd. per hr. It began operation with a fleet of 10 transit mixers. When Forsyth plant went into operation, 20 of same trucks were added to fleet to serve both plants. Aggregates at new plant are discharged into steel hopper and belt-conveyed to three compartments of a 166-cu. yd. steel bin. Aggregates are conveyed to top of plant where a swivel chute deposits them in four of five compartments concrete bin; the fifth compartment of 250 bbl. capacity, is for cement. Aggregates are sand, two grades of gravel, and one grade of crushed stone. Bulk cement is unloaded from cars and pumped by pneumatic system to two concrete storage silos, from which it is moved, as required, to the 250-bbl. cement compartment by same 5-in. pump. Aggregates are fed through radial gates and cement is fed through a rotary valve into weigh hoppers. Each hopper has a scale with a weightometer attachment. Contents of the two weigh hoppers are discharged to charging hopper which, in turn, discharges mix dry into truck. Water is fed simultaneously to tank on truck. Deliveries are usually within a radius of five miles. Distances of 20 miles are not unusual. Most of market for concrete is for laying sidewalks and highways.—A. J. HOSKIN

Construction of the North Lock in Bremerhaven (Germany). A. AGATZ. *Report 33rd. main meeting German Concrete Association*, March 17, 1930, p. 324-88.—Author gives extensive description of enlargements and new constructions of North Lock. Entire construction program covers: (1) Outer harbor, 1148.3 ft. long, 393.7 ft. wide at harbor entrance and 262.5 ft. wide at lock entrance; depth of water along breakwater is 52.5 ft. (2) Lock, 1220.5 ft. long and 196.8 ft. wide with 47.6 ft. of water and 147.6 ft. wide passage opening. (3) Turning basin, 1312.3 ft. long and 787.4 ft. wide; depth of water is 42.7 ft. (4) Connecting canal, which is 147.6 ft. wide. (5) Swing-bridge, distance between rest piers is 367.2 ft., main girders are placed 53.1 ft. apart and carry two railroad tracks for freight and passenger service, one wide roadway and a 9.2-ft. wide cantilevered sidewalk. (6) Enlargement of inner harbor to a length of 984.3 ft. and a depth of 42.7 ft. (7) Extension of a dock from 879.3 ft. to 1099.1 ft. Work was started in 1927 and will probably be finished in 1931. After its completion, this harbor will be one of greatest European ports and capable of meeting greatest traffic and largest ships. Over 400 holes were drilled to depths of 164 ft. to study underground conditions. Results of this investigation are given in details. Axis of new outer harbor structure is about 154.2 ft. farther west than axis of old harbor. Construction of break-water and harbor walls was carried out in great number of divisions for which 20 different cross-sections were calculated according to variations of underground. Concrete walls rest on wooden pile foundations, which were more resistant than concrete piles in this particular kind of sea water. About 600-lbs. blast furnace slag cement and 100-lbs. trass were used for 35.3 cu. ft. of concrete. Top of walls was provided with 20-in. wide strip of basalt slabs roughness of which facilitates walking. Steel sheet pilings of Larrsen type were used for wall construction. Inner and outer head of lock are of similar design and were built under considerable difficulties due to bad underground. Construction was of reinforced concrete after lowering groundwater level. Bottom slab is 21.3 ft. thick. Water pipes are shaped like trumpets in order to furnish favorable flow conditions. Lock can be filled in 18 to 29 minutes. Shape and reinforcing of heads are illustrated in several drawings. Smallest width is 32.8 ft. greatest 39.7 ft. and height is 65.6 ft. Gates are of sliding type, 27.9 ft. wide, 62.3 ft. high and 152.9 ft. long. Steel structure of swing-bridge rests on heavy reinforced concrete foundation constructed between steel sheet pilings on sound underground. Two end piers rest on wooden pile foundations. Three engine houses were erected for operation of gates and swing bridge. It is also necessary to build a 220 ft. extension to old dock, which is now 879.3 ft. long. Ten different cross-sections are calculated and discussed. New dock will be able to hold ships with capacities of 80,000 tons. Last part of article gives data about amount of consumed structural materials,

volume of excavations, arrangement of site of construction, progress of construction program and general information. (cf. *Bautechnik* (Germany), June 6, 1930, V. 8, No. 25.)—A. E. BEITLICH

Precast concrete balconies. *Conc. Building Conc. Products* (England), Dec., 1930, V. 5, No. 12, p. 162.—An illustration is given of a new type of precast concrete balcony for use in cinemas and theatres. The treads and risers are precast in one unit with continuous reinforcement, and at the back of tread on underside, is a notch to fit rolled steel joist supporting the stepping. On top side is another notch to receive the riser above. The risers are 2½ in. and the tread 3½ in. thick. The edges are formed to make joggled joints, and strips of wood are cast in the treads for nailing floor boards, etc.—JOHN E. ADAMS

Omaha firm sells both central-mixed and mixed-in-transit concrete. *Pit and Quarry*, Nov. 19, 1930, V. 21, No. 4, p. 40-43.—Ready Mixed Concrete Co., Omaha, Neb., has new central plant to produce concrete by two methods. Aggregates and cement flow by gravity from respective hoppers into weighing batchers and then to truck-loading chute. The aggregates hopper has two compartments of combined capacity of 75 cu. yd. Cement hopper holds 20 tons. Cement's flow to batcher is controlled by a dumping gate. A timing dial on aggregates scale indicates approach of correct weight. Batch hopper has a capacity of 10 tons. The cement batcher has a capacity of 2,500 lb. and has a similar scale. A small 110-volt vibrator is mounted on cement-discharge to prevent cement from sticking. Water is measured volumetrically from a square steel tank by a short length of pipe inside the tank capable of being raised or lowered to vary the quantity of water withdrawn in 5-gal. units, up to 120 gal. "Sand-gravel" in this field means mixture all of which will pass 1-in. mesh, and 50 per cent of which will not pass a No. 10 screen. This aggregate is received in carloads at plant, and is handled directly from storage into hoppers. Cement, purchased in bulk, unloaded from cars by power shovel into small receiving hopper at ground level. Thence it passes to the cement hopper or to storage. As needed stored cement is fed again to the bucket elevator. Delivery of concrete is made free of charge within Omaha city limits, with a charge of 25¢ per cu. yd. mi. elsewhere. Four mixes are standardized and sold under guaranteed strengths varying from 2,000 to 3,600 lb. per sq. in. An electric system of communication enables the shipping clerk in his office to flash a series of numerals at the batching operator's station to indicate the quantity of an order and the mix.—A. J. HOSKIN

Concrete bulkheads for creek channel improve Jacksonville swamp area. (See ENGINEERING DESIGN—MISCELLANEOUS.)

Concrete block tunnel lining. (See SHOP MANUFACTURE.)

Reinforced concrete window frames. (See SHOP MANUFACTURE.)

Some new prospects in the development of the concrete products industry. (See SHOP MANUFACTURE.)

ROADS AND PAVEMENTS

Rigid inspection produces better pavements. *Eng. News Record*, Jan. 8, 1931, V. 105, No. 2, p. 77.—Supervision of contract paving in Detroit by city engineer's office during last 6½ years has increased the 28-day strength of drilled cores by 25 per cent. By making richer mix, eliminating soft, dusty limestone aggregate, and increasing the time of mixing, the average 28-day compressive strength of drilled cores has been increased to more than 3200 lb. per sq. in.—GLENN MURPHY

Truck operation and production in concrete paving work. A. P. ANDERSON. *Public Roads*, Feb., 1931.—Analyses of time losses in production suffered by reason of either an insufficient supply or faulty operation of hauling equipment used in concrete road construction, and results of studies on 100 concrete paving jobs show an average time loss of 17 per cent due to these causes. These time losses may be considerably reduced by applying a number of governing principles which are discussed in detail in the report indicating importance of properly designing the material yard layout and shows the amount of loss due to faulty layout. Tables and charts are included from which the proper number of trucks to use under any given set of conditions may be computed. Contract hauling is not in general profitable to contractor, because conditions are often such that greatest profit to hauling contractor accrues at rather low rates of production.—F. H. JACKSON

A study of methods of curing concrete pavements. F. H. JACKSON AND E. W. BAUMAN. *Public Roads*, Jan., 1931.—In field investigation in Tennessee conducted jointly by the Bureau of Public Roads and Tennessee Department of Highways, experiments were conducted on a concrete pavement approximately 15 miles long, pavement on one side of longitudinal joint being cured in 1000-ft. sections with the various curing methods under consideration while concrete on other side of joint was cured with earth and water in the conventional manner for comparison purposes. The following methods of curing were investigated: Wet burlap applied for 12 to 96 hrs.; no cure; Sisalkraft paper applied for 24 hrs.; sodium silicate—earth subgrade, tar paper on subgrade; calcium chloride, surface application—earth subgrade, tar paper on subgrade; Hunt process—earth subgrade, tar paper on subgrade; Barber asphalt emulsion (curcrete)—earth subgrade, tar paper on subgrade; Headley asphalt emulsion—earth subgrade, tar paper on subgrade; Tarvia K. P.—earth subgrade, tar paper on subgrade; Tarvia B—earth subgrade, tar paper on subgrade; poor earth cure; ponding; calcium chloride admixture—earth subgrade, tar paper on subgrade. Total length of pavement tested was 74,148 ft. A large number of concrete beams and cylinders were made and tested and results analyzed in detail. In addition results of two detailed crack surveys of pavement are given. Conclusions as to relative efficiency of various curing methods are based on consideration of strength developed by concrete beams cast alongside pavement sections and cured in same manner, concrete cores drilled from the pavements and the results of crack surveys. Efficiency of curing method as applied to each section was determined by comparing results for that particular section with results obtained for the standard water cure on the same section. In this way accidental variables such as subgrade conditions, etc., were largely eliminated. It is believed that results of this investigation justify following comments relative to merits of various curing methods as compared with standard method of curing with earth and water, under conditions prevailing during progress of these tests: 1. *Burlap curing*—Method of cure involving application of wet burlap for periods varying from 24 to 96 hr. without further curing compares quite favorably with standard method. No final conclusions can be drawn until additional tests under more severe weather conditions are made. 2. *Sisalkraft paper*—Application of Sisalkraft paper for periods of 24 to 48 hr. without further curing is a reasonably satisfactory method of cure compared with standard method. 3. *Poor earth cure*—It is not necessary to keep earth saturated with water for entire 10-day curing period. 4. *Sodium silicate*—This method of cure gives results somewhat less satisfactory than those given by standard method. 5. *Calcium chloride, surface application*—Results very nearly as satisfactory as standard method. 6. *Calcium chloride admixture*—Sections on which admixture was used are too short to warrant any conclusion as to merit of this method. 7. *Bituminous materials*—Curing with bituminous materials, as used in these tests, is unsatisfactory, because of the marked evidence of increased transverse cracking. 8. *Tar paper on subgrade*—Nothing is gained by its use.—F. H. JACKSON

SHOP MANUFACTURE

To prevent cracks in masonry walls. W. D. M. ALLAN. *Concrete Products*, Jan., 1931, V. 40, No. 1, p. 27-29.—This article was prepared to provide products manufacturers with information to refute the claims of competing materials that cracks necessarily occur in concrete masonry. A number of drawings illustrate the best methods of preventing cracks.—E. S. HANSON

Long established pipe plant adopts machine manufacture. *Concrete Products*, Feb., 1931, V. 49, No. 2, p. 20-23.—The Core Joint Concrete Pipe Co., at Irvington, N. J., which has been manufacturing hand made pipe for a number of years, has recently added a department for making pipe by machine, the process being of particular interest in that it provides for lining the pipe by machine at the same time as it is manufactured. A mix is applied hot and automatically trowelled into the wall of the freshly made pipe. This liner mix is composed principally of specially graded sand, slate flour and ordinary paving asphalt.—E. S. HANSON

Das betonwerkstein (cast stone) TAMMS. *Betonwerk* (Germany), Dec. 21, 1930, V. 18, No. 51, p. 715.—In present methods of making cast stone discussed, aggregates are selected for their durability and appearance, carefully graded and recombined. The surface of the cast product is cut to resemble cut stone. It is suggested that this method may not be ideal but a surface which reflects the mold in which it is cast may produce a product more in keeping with the nature of concrete. Under certain conditions such as with the use of a hard aggregate the employment of the sand blast may produce interesting surfaces, also the Contex method is suggested in that individual grains or aggregates are fully exposed. Examples in France and America are cited, especially, several examples of work done by Frank Lloyd Wright in California.—H. FRAUENFELDER

A new column fireproofing unit. ROBT. H. MOORE. *Concrete Products*, Jan., 1931, V. 40, No. 1, p. 22-23.—Segmental units for fireproofing steel columns were developed by the Detroit Cinder Block & Tile Co., Detroit, Mich., for use on one particular job but have proven so successful as to be added to the regular line of products. These are made in circular and octagonal shapes, the circular units three to a circle and the octagonal two to a circle. The units are 2 in. thick and 8 in. high, with the length depending on the size of the column to be fireproofed.—E. S. HANSON

Profitable manufacture of concrete building units. FRED A. SAGER. *Concrete*, March, 1931, V. 38, No. 3, p. 27-29.—With approximate idea of space requirements of each part of manufacturing process, preliminary block plan may be drawn up. Use of outline sketches of various parts of plant, drawn to same scale as property site and cut out on separate pieces of paper, to be arranged in various combinations so that advantages of different locations may be studied, is suggested. Two fundamental characteristics of layout should be arrangement for future extension, and one-direction flow lines for material through the plant. Equipment space includes area for elevator and crusher adjacent to cinder storage and for boiler near coal storage, all located near railroad siding. Manufacturing plant includes two standard block machines, brick machine, hand-operated machine, mixer, motors, storage for pallets, etc. Advantageous stock-piling and area required are determined. Diagram illustrates provisions for materials, equipment and traffic.—C. BACHMANN

New product gave us our best year. C. V. BERRY. *Concrete Products*, Feb., 1931, V. 49, No. 2, p. 17-19.—Addition of manufacture of concrete floor

joists gave a products manufacturer in Kalamazoo, Mich., a successful business during 1930 in spite of unfavorable conditions. These floor joists are shaped somewhat like a steel I-beam, having top and bottom flanges 3 in. wide and a web thickness of 1¼ in. The section is made 8 or 10 in. high and up to 20 ft. in length. Adequate tensile and sheer reinforcement is provided in a welded unit to resist externally imposed loads with an ample factor of safety. Sand and Haydite are used as aggregates, the mixture being proportioned as 1 part cement, 2 sand, 2 fine Haydite and 4 coarse Haydite. Special equipment has been developed for manufacturing these floor joists approximating somewhat the method of rolling steel rails in a steel mill—E. S. HANSON

Concrete sign posts. *Conc. Bldg. Conc. Prod.* (England), Feb., 1931, V. 6, No. 2, p. 18.—Precast concrete sign post, made with colored cements, results in saving of maintenance costs. Posts could be in white cement, and the arms white with black letters or vice versa. Cap could be of any standard design. Letters are cast separately and attached to arms later, arms being left with a rough face. Rough surface may be formed by fixing ½-in. mesh wire netting to the panel which forms sinking for letters, so when the side forms are released netting comes away also, leaving a surface with a good key. Letters should be ⅝ in. in thickness with ⅜ in. embedded in concrete, and composed of 1:2 mix with clean sharp sand. Fixing is done with a slight skimming of neat cement and filling made with 1:3 mix in the desired color. The suggested mixes are as follows: 1:1½:3 (½ in. to ⅛-in. ballast with clean sand or stone dust) for posts; 1:1½:3 (⅜ in. to ⅛ in. as above) for arms and caps. Reinforcement for post should be four ½-in. rods with ⅛-in. wire ties at 12-in. centres, and with 1-in. cover. For arms two ⅜-in. rods tied at 6-in. centres are recommended.—JOHN E. ADAMS

Concrete block tunnel lining. ERNEST H. ROWE. *Concrete Products*, Jan., 1931, V. 49, No. 1, p. 12-14.—Manufacture and installation of segmental concrete block for lining one of extensions of New York's system of rapid transit subways include interesting details. The bid of the successful contractor was $387.00 per lineal ft. of lining as against $524.00 per lineal ft. for cast iron lining. In addition to the money saving the concrete block tunnels were completed in much less time than cast iron tunnels. Ten blocks per ring were specified, outside diameter of ring to be 3 ft. greater than inner diameter which was 16 ft. 9 in. Each block was 5 ft. 2⅞ in. on the arc of the concave face with a width of 2 ft. 6 in. and a radial thickness of 18 in. Forms for each block were set up on a car and the cars handled in trains of 30 under mixer. Each block was reinforced with two mats of five ⅜-in. rods. Interlocking of the rings was provided for by two projections, on one side, and corresponding depression on opposite side.—E. S. HANSON

Reinforced concrete window frames. W. CHRISTEN. *Beton u. Eisen* (Germany), Oct. 20, 1930, V. 29, Heft 20, p. 375-377.—The speed with which modern structures are being erected has created a demand for factory-built and standarized building units. These units lead to an improvement of the construction and to lower costs. Window openings had formerly been built up on the job of separate precast units or of brick. Necessity of economizing on labor has led to quantity production of reinforced concrete window frames—a product which has come into greater use in the last few years. Advantages of this ready-built unit are: more effective and exact construction; lighter weight (a frame unit with 4 ft. 7 in. by 3 ft. 9 in. opening weights 310 lb. as against 1210 lb. formerly necessary); easier erection. In order to further the use of this type of unit it is necessary to standardize openings and frame sections. Experience has shown that less than 20 pieces of one type cannot be manufactured at a price low enough to compete with the older methods. (Abstractor's note: In accordance with German practice these frames are all for casement windows.)—A. A. BRIELMAIER

Media plant pioneers in manufacture of light-walled units. J. J. BUZZELL. *Concrete*, March, 1931, V. 38, No. 3, p. 21-22.—Media Concrete Products Co., Inc., Media, Pa., has successfully developed light-weight building unit of improved design, using ordinary aggregates. In addition to old style standard sizes, units 7¾ by 7¾ by 15¾ in. and 7¾ by 11¾ by 15¾ in. have been adopted. Fifty per cent air space was found most satisfactory. Mortar bed of 1½ in. is provided due to sharp flare at top ledge. Units are manufactured in two classes. First employs combination of hard aggregates resulting in dense concrete, not nailable but intended for underground work. 7¾ by 7¾ by 15¾ in. size weighs 36 lbs., and 7¾ by 11¾ by 15¾ in. size weighs 45 lb. Other type of light-walled unit provides extreme light-weight and free nailability with slight crooking of nail. 7¾ by 7¾ by 15¾ in. size weighs 30 lb. and 7¾ by 11¾ by 15¾ in. size weighs 38 lb. Besser senior stripper and 25-ft. mixer, and one size plain pallets for all units are used. Air-tight steam enclosures at siding are provided for thawing out cars of freezing aggregates. Large block storage area is at car level adjacent to siding, so cars may be loaded by rolling units from stock-piles into cars. Overhead storage capacity is divided into nine separate, covered bins equipped with steam heating facilities. Mixer floor is directly beneath overhead bins, mixer hoppers are fed from any bin desired by 18-in. cross conveyor and machines are located directly under mixers on lower floor. Arrangement of racks around machines allows continuous machine operation, using electric industrial track.—C. BACHMANN

Some new prospects in the development of the concrete product industry. R. JECHT. *Beton u. Eisen* (Germany), Oct. 20, 1930, V. 29, Heft 20, p. 368-370.—The profitable manufacture of concrete units depends on two conditions; a large or steady demand for same product, need or economy of high-quality product for special purpose. The first condition has led to mass production of pipes, slabs, poles, etc. In some cases the same product satisfies both conditions. Class of units meeting second condition is not clearly defined. A high-quality product requires long experience, expensive experimental work and thoroughly trained workmen. Best results of progress made in concrete proportioning and treating can be realized only in permanent factory with experienced personnel. Progress in widening the field is marked by costly failures. Aim to manufacture units which will utilize, on the job, modern transportation and erection equipment is correct. Only in this manner can concrete products benefit, as steel has done, from progress made in erection equipment. A few examples follow: Highway viaduct in Klingenberg, Saxony, is built of A—frames with centrifugally-cast poles up to 56 ft. long. Frames are stiffened longitudinally by the deck and at about one third height by two horizontal members from frame to frame. The corners and connections were made secure after erection by pouring mortar in the joints or casting a concrete block around them. The form costs for pouring this job on the site would have been prohibitive. Units for poles and towers for pipe lines and high tension lines have come into use but face a very strong competitor in steel, due to the present low steel prices. In Italy where the position of steel is not so strong, these towers have been more widely used. Recently in the improvement of Konigsberg Sea canal 60 three-pile (centrif-cast) foundations were used for sea beacon bases. These piles are exposed to a strong ice pressure. Use of precast units, as wall panels, roof slabs, has proved economical for garages and other small jobs. In Germany the use of concrete water pipes is just becoming noticeable while in other countries much progress has already been made. Here again the centrifugally-cast product is in the lead.—A. A. BRIELMAIER

Technique and form in cast stone. (See ARCHITECTURAL DESIGN.)

Precast units in slab construction. (See FIELD CONSTRUCTION—Miscellaneous.)